REGIONAL GEOLOGY OF THE UNITED STATES OF NORTH AMERICA

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WITH A CHAPTER ON THE LITHOLOGY

BY

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U. S. GEOLOGICAL SURVEY

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United States of North America

by

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I. Morphological Summary.

Position.

Being merely a political division of North America, the United States of America does not constitute a natural geographic region. It occupies most of the southern half of North America, or, more exactly, it lies between the drainage of the St. Lawrence River and the 49th parallel of north latitude, on the north, and the Gulf of Mexico and the republic of Mexico, on the south. Its geologic and geographic features are continued northward in Canada and southwestward in Mexico.[1]

Topographic Divisions.

Physiographers are not agreed as to the classification of the varied surface features of the country.[2] For convenience it may be divided simply into six parts. a) In the

Fig. 1. Physiographic provinces of the United States.

[1] The outlying dependencies of the United States, such as Alaska, Porto Rico and the Philippine Islands are not included in this description.

[2] Powell, J. W., Physiography of the United States. Am. Book Co., New York, 1895 pp. 98—99.

Davis, W. M., Physical Geography, Ginn & Co., Boston, 1899.

middle lie the great interior plains sloping inward to the Mississippi river and southward to the Gulf of Mexico, and interrupted by a few low mountain groups. b) On the east side, these are enclosed by a low plateau and mountain ranges (Eastern Highlands) which are in turn bordered by c) a coastal plain. d) West of the interior plains lie the Rocky Mountains, e) the dry western plateaus, and finally f) the Pacific ranges. The six chief regions may be subdivided into smaller provinces and considered in more detail.

Eastern Highlands.

From the northeast corner of the United States a belt of highlands stretches southwestward about 2100 kilometers to the state of Alabama. Its varied topography includes mountains and thoroly dissected plateaus. The northern part has been modified by glaciation, but the southern not. In general the mountains are low, rounded, and clad with forests. Only a few of the highest peaks rise more than 1600 meters above sea-level.

The highlands may be subdivided into several smaller physiographic features. From Alabama to New York there is a central chain consisting chiefly of long mountain ridges caused by the outcropping edges of folded hard strata. In North Carolina the mountains culminate in Mt. Mitchell (2050 meters), the highest point in eastern United States. The average elevation of the summits is, however, only 800—1200 meters. A northeastern continuation of the folded ranges passes from the Hudson river thru northwestern New England to the apex of the state of Maine. Among them are some notable heights, such as Mt. Washington in New Hampshire (1915 meters) and Mt. Kathadin in Maine (1585 meters).

In northeastern New York, the Adirondack mountains rise as a nearly isolated group, which is physiographically a dissected dome-shaped uplift. Mt. Marcy, the most elevated peak, stands 1780 meters above the sea.

The entire mountain system from Maine to Alabama is loosely called the Appalachian Mountains, although the name applies strictly to the ranges of folded Paleozoic rocks southwest of New York.

On the northwest the mountain system is flankt by a maturely dissected plateau 600—1000 meters high, called in the north the Alleghany, and in the south the Cumberland plateau. The whole is now generally named the Appalachian plateau. The strata are nearly horizontal and chiefly of late Paleozoic age.

On the southeast lies a parallel strip of hilly country in which the rock structure is but feebly expresst in the topography. This is the Piedmont region. It forms a transition ground between the mountains and the coastal plain. Complex schistose rocks are everywhere worn down to a low plateau trencht by many valleys of inconsiderable depth. The moist climate gives it thick residual soils and a luxuriant growth of vegetation.

The continuation of the Piedmont plateau east of the Hudson River has been called the New England plateau. It differs from the rest of the Piedmont chiefly in having been modified by glaciation. Its many lakes, deranged drainage and morainic soils it owes to the work of the Quaternary ice-sheets. In New England, alone, the Piedmont belt touches the Atlantic Ocean. Its coast is markt by rocky bays and inlets with narrow beaches. Along the coast of Maine fiords are numerous. These features contrast with the sandy shelving border of the coastal plain farther south.

Coastal Plains.

The highlands are bordered on the east by a gently sloping coastal plain which has been carved from the weak sedimentary rocks of Cretaceous and later age. The junction of the coastal plain and the Piedmont belt is accentuated by a low terrace

over which rivers pass with steepened slopes to the flat valleys below. From the fact that rapids or low falls are found in nearly every stream as it crosses this boundary, it has been called the „fall-line“. The fall-line marks the head of navigation on the coastal rivers, and for this reason, as well as for the available water power, many cities, such as Philadelphia, Richmond, and Raleigh, have been built there. Below the fall-line shallow valleys have been cut into the coastal plain. As a result of the recent subsidence of this part of the coast many of the valleys expand sea-ward into navigable estuaries, such as Chesapeake and Delaware Bays. Southwestward the Atlantic coastal plain merges into the similar plain which partly encircles the Gulf of Mexico. The peninsula of Florida is a low extension of the coastal plain. The coast is bordered thruout by bays, swamps and lagoons, which are generally hemmed in by sandy wave-built reefs. Southern Florida, particularly on the western coast, is edged with coral reefs and extensiv mangrove swamps. A great belt of sand is drifting along the east shore under the influence of northern littoral currents.

In general the Gulf coastal plain is like that of the Atlantic slope. It is the great fertil agricultural region of the southern states,—the cotton and sugar belt. Centrally it includes the broad swampy flood-plain and delta of the Mississippi river, more than 250 kilometers wide, which stretches northward as a deep embayment beyond the mouth of the Ohio river. The Gulf plain, which is 350—500 kilometers wide, is bounded on the south by a swampy muddy coast fringed here and there with sand-bars. On the landward side it merges into the hilly plains of the vast interior low-land, or, as in central Texas, is more sharply separated from the western plateaus by low fault scarps and terraces.

The Gulf coastal plain presents a variety of climatic and biologic conditions. On the east it is moist and partly forested. In Texas, by imperceptible gradation, it enters a drier region, and becomes a land of grassy prairies; altho near the gulf the climate is sufficiently moist for the growth of cotton, sugar and even rice.

Interior Plains.

The central part of the United States consists of a wide open lowland, most of which is drained by the Mississippi river and its many tributaries. The Mississippi it-self forms a north-south axis, on each side of which the surface rises gradually to the distant mountains. The eastern slope is drained largely by the Ohio river system. The western slope is the watershed of the Missouri, Arkansas, and Red rivers.

On the eastern slope, south of the Ohio river, the lowland is dissected into sub-dued hills with wide flat-bottomed valleys. Much of the region is populous and fertil. It was formerly covered with forests of deciduous trees. Eastward it ranges into the hilly Appalachian plateau.

North of the Ohio river a surface once maturely dissected has been transformed topographically by recent glaciation. There the relief is even less than south of the Ohio. Broad gently rolling plains alternate with smaller areas of somewhat rougher hills where the ice-sheets left terminal moraines. In Minnesota, Wisconsin and Michi-gan, within the limit of the last ice-sheet, there are thousands of lakes and swamps. Much of this region was once well forested, but the forests have been largely removed during the last century. The southern portion is fertile and well populated, but in the northern states large areas are still but sparsely inhabited. In the vicinity of Lake Superior some highlands rise above the general level of the rolling plains. Here complexly folded ancient rocks protrude, and irregular rock hills are interspersed with swamps and lakes. The topography may be compared to parts of Finland.

West of the Mississippi river comparativly weak flat-lying strata have been thoroly dissected leaving wide flat valleys separated by low hills, many of which have flat tops. The rocks are chiefly of Carboniferous age in the east, and of Cre-

taceous and Tertiary age in the west. Of the rivers which cross this region the largest rise in the Rocky Mountains, but the short tributaries have their sources in the plain itself.

That portion of the plain between the Missouri and Mississippi rivers, including such states as Iowa and Missouri, enjoy moderate rainfall but a wide range of temperature. It was originally a land of grassy prairies with forests along the streams, and now, being thoroly cultivated, it produces great crops of corn and wheat. The western part of the plain near the Rocky Mountains is semi-arid and clad only with sparse grasses. It is a grazing country, and crops can be raised successfully only in wet years or where irrigation is possible. In some portions of this dry western plateau region, the rapid erosion of unprotected Tertiary clays has given rise to fantastic and extremely irregular canyons and ridges, which are known collectivly as „the Bad Lands". On the southwest the „Great Plains" pass gradually into mountainous plateaus, with increasing aridity of climate. Near the border-line between these two provinces lies the „Llano Estacado"—a low plateau with a steep dissected slope facing the coastal plain of Texas. The name is derived from the fact that the plain is covered with tall cacti, almost the only conspicuous features of the landscape.

Not all of the great interior region is a plain. In southern Missouri and northern Arkansas a flat dome of Paleozoic rocks forms a low plateau which stands 200—300 meters above the surrounding plains. It is deeply dissected by many streams so that the plateau is in fact a group of low mountains in nearly horizontal strata. In many respects it resembles the Appalachian plateau, altho it is not so high. Like it, the Ozark plateau is forested and the population scattered.

South of the Arkansas river in Arkansas and southern Oklahoma, there are parallel ranges of low mountains which owe their position to folded Paleozoic rocks and isolated patches of pre-Cambrian granite. Structurally, they bear a close resemblance to the folded ranges of the Appalachian system and it is possible that they are actually a westward continuation of those mountains. The ranges have a relief of 300—500 meters. They are separated by wide flat valleys and, especially in the west, are almost isolated in the surrounding plains.

In the northwestern part of the Great Plains lies another dome which is historically a part of the Rocky Mountain system, but is so completely isolated that it may be considered with the plains. The dome, consisting of gently inclined strata, has been truncated and dissected into a group of low mountains standing 300—800 meters above the plains. It was early named the Black Hills, because of the contrast between the dark wooded hills and the prevailing yellowish brown or gray color of the surrounding plains.

Western Mountains and Plateaus.

From the interior plains to the Pacific Ocean, a distance of about 1500 kilometers, successiv mountains and plateaus make a rugged surface. These may be divided readily into three major features: a mountainous plateau, with a great system of higher ranges on the east side, and another equally conspicuous but narrower system on the west. The plateau, for want of a better name, may be called the Basin plateau. The eastern mountains form part of the great Rocky Mountain system, which extends northward into Canada, and southward into Mexico. The western mountains belong to the Pacific Mountain system which likewise has extensions north and south of the United States.

This vast area, nearly one-third of the United States, includes three large drainage basins besides many of smaller size. The Columbia River on the north and the Colorado River on the south flow westward to the Pacific, altho their headn waters are intertwined the recesses of the Rocky Mountain chain. The intermediate

part of the plateau has no outlet to the sea, but the drainage leads into many isolated desert basins, the largest of which contains Great Salt Lake in Utah. The Rio Grande drains the southern part of the Rocky Mountains and many comparativly short streams descend the western slope of the Pacific mountains to the ocean.

Rocky Mountains.

Immediately west of the Great Plains lies a plexus of ranges and irregular groups of mountains with roughly parallel trends. It passes thru the states of New Mexico and Colorado, and thence thru western Wyoming, Montana and the borders of adjacent states. The continental divide, separating the drainage systems tributary to the Pacific from those of the Atlantic, follows this mountain chain thruout.

The highest and broadest part of the Rocky Mountains occupies much of Colorado. The numerous mountain ranges rise to elevations of 4000 to 4300 meters, but inasmuch as they are based upon a high plateau, their actual relief is generally but 1200 to 2000 meters. Most of these ranges consist of pre-Cambrian granite and metamorphic rocks, or of tilted Paleozoic strata. The mountain chains are separated by wide flat valleys locally known as „parks". Most of these valleys occupy synclines filled with soft Mesozoic or Tertiary rock.

From Colorado northwestward the ranges are somewhat more dispersed, many of them rising isolated from the surface of the Wyoming and Montana plateau, which is in reality a westward continuation of the Great Plains. Along the western edges of Wyoming and Montana, however, the ranges are more closely grouped. There is situated Yellowstone National Park with its wonderland of hot springs and geysers. Near the northern boundary of the United States few of the summits of the Rocky Mountains stand more than 3000 meters above sea level, but they are even more rugged than farther south, because they have been more severely glaciated.

From Colorado southward the mountains decrease rapidly in height, and merge into arid plateaus surmounted by isolated ranges in the states of New Mexico and Texas.

Intermontane Plateaus and Ranges.

The vast intermontane region which occupies most of the states of Idaho, Utah, Nevada, and Arizona, with much of eastern Washington, Oregon and California, is not to be thought of as a featureless plateau. The surface is diversified with scores of mountain ranges separated in many places by wide flat valleys. The southern portion of the region is largely a desert, but in the north the climate is not so dry but that wheat may be grown without irrigation. Altho it is not possible to draw definit boundaries within this region, three fairly well-defined divisions are recognizable, as shown by Powell[1]:—the Columbia plateau in the north, the Basin ranges in the middle and the Colorado plateau in the south and southeast.

The Columbia River and its largest tributary, the Snake River, flow thru a plateau which has an average elevation of 500 to 1,000 meters above sea level. This plateau consists largely of successiv basaltic lava flows which were poured out over the surface in early and middle Tertiary times. The flows filled the irregularities of a surface which had been sculptured from ancient metamorphic rocks. In comparativly recent times the rivers, chiefly the Columbia and its branches, have trencht the plateau with narrow canyons. Along the northern edge of the plateau large Pleistocene glacial lobes, descending from Canada, left deposits of till and outwash which have modified the topography in detail, and also have contributed to the for-

[1] Physiography of the United States, by J. W. Powell and others, Amer. Book Co., New York, 1895.

mation of a rich soil. This part of the Columbia plateau is today one of the greatest wheat-raising districts in the United States. The southern and southwestern parts of the lava plateau have much less rainfall, and are essentially deserts. Here and there isolated mountain groups of older rocks rise like islands surrounded by the lava flows. One of these is the Blue Mountains of northeastern Oregon.

Southward the lava plateau passes gradually into a region of parallel mountain ranges, separated by flat arid basins and valleys, most of which are without streams. Many of the ranges have abrupt fronts and gentle back-slopes, and have been interpreted as normal fault blocks. Others are irregular in form and believd to be deeply eroded resistant portions of a much folded mass of rocks. Along the edges of the mountain ranges alluvial fans from many ravines extend out into the wide valleys, where they combine to form vast alluvial slopes. In the midst of many of the valleys there are saline lakes and playas, or, where lakes no longer exist, their former presence is shown by deposits of fine clay and precipitated salts. The largest lake now remaining is Great Salt Lake in Utah. In eastern Nevada a group of lakes are the remnants of a once larger body of water to which the name „Lahontan“ has been given.[1] Except that of the Colorado River basin, drainage of this part of the plateau does not reach the sea, the short mountain streams generally disappearing in the porous deposits which mantle the bases of the ranges.

In New Mexico, Arizona, and southern Utah, the mountain ranges are partly replaced by broad terraced plateaus, which rise to elevations of 1800 to 2400 meters above sea level. On account of the aridity of the climate all but the highest of them are treeless. The plateaus are bordered by precipitous cliffs and talus slopes. They are cut by deep canyons of which the majority are tributary to the Colorado River and Rio Grande. The Grand Canyon of the Colorado itself is now famous as one of the greatest of all canyons and is visited yearly by hundreds of tourists attracted by the vivid grandeur of its scenery.

Pacific Ranges.

Between the plateau region and the Pacific Ocean lies a broad mountainous belt which can be roughly separated into three longitudinal divisions. A higher range on the eastern side is parted from a lower range near the coast by a series of broad depressions. The eastern range is called the Sierra Nevada in the south and the Cascade Range in the north, while the western range is called the Coast Range in the south and the Olympic Range in Washington. The depressions between are not continuous. In the south the great valley of California is occupied by the Sacramento and San Joaquin rivers, while in the north there is the depression occupied by the Willamette River in Oregon and Puget Sound in Washington. Between the valleys is the dissected highland of the Klamath Mountains.

The Sierra-Cascade ranges are high, and their loftier peaks rugged from glacial sculpturing. The Sierra Nevada is bounded on the east by an abrupt fault scarp, but the Cascade Range has no such feature. The highest peak in the United States is Mt. Whitney, the culmination of the Sierra Nevada in southern California. Its elevation is 4540 meters. In the northern part of the range several large and apparently extinct volcanos rise along the western flank of the Cascade Range. Mt. Shasta, Mt. Hood, and Mt. Rainier are the most conspicuous of these and are among the grandest peaks in the United States. All are covered with snow and glaciers, and bear the marks of eruptions in recent geologic times. Activ fumaroles and steam vents suggest that some of them are now merely dormant.

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[1] I. C. Russell, U. S. Geol. Survey, Monograph XI (Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada), 1885.

The Coast Ranges are much lower and less rugged. They are interrupted here and there by valleys, as at San Francisco, Portland, and the Klamath River. There is a markt climatic change from south to north, and the vegetation and topography vary correspondingly. In the drier southern portion the Coast Ranges present bold ridges and cliffs largely devoid of tree growth, while in the north the summits are rounded, and dense coniferous forests clothe the slopes.

In the depressions between these ranges lie some of the most fertil and prosperous communities of the western states. The great valley of California is cultivated largely thru the aid of water taken from the mountain streams, and is one of the chief seats of the fruit-raising industry in the United States. Farther north the cities of Portland, Seattle and Tacoma are situated in the corresponding valleys, and the submerged northern continuation of the same depression affords the splendid harbor of Puget Sound.

II. Stratigraphy and Formations.[1]

Introduction.

In the broad area of the United States all geologic systems are represented. Some of them, however, are not widely distributed and include mostly non-marine deposits, many of which lack fossils.

In general, the formations older than the Cambrian are found chiefly in the northeastern and eastern parts of the country and in scattered areas among the western mountains. The Paleozoic systems are best known in the eastern interior, but they are found also in many parts of the West. The Mesozoic rocks are exposed chiefly in the Great Plains and Rocky Mountains, and also around the borders of the continent east, south, and west. The marine Tertiary formations form a narrow fringe along the coasts, while those of terrestrial origin are widely distributed among the western mountains and the adjacent plains. The Quaternary glacial drift has its widest distribution in the north-central and northeastern parts of the country.

Archeozoic (Archean).

General Characteristics.

The rocks of the Archean system are almost entirely metamorphic or igneous. They comprise greenstones, gneisses and schists with intrusiv granites, syenites, gabbros, porphyries, and many other rocks. Some of the metamorphic rocks, such as the greenstones, are obviously of igneous origin. One of the commonest types seems to consist of moderately altered lava flows and breccias. A small portion of the Archean system is clearly of sedimentary origin, being composed of black slate, quartz schist and jaspery iron formation. A large part of the system has been so highly metamorphosed however, that its origin is still doubtful.

The mutual relations of the different kinds of rocks within the system are usually complex. They have been repeatedly subjected to folding, and the intrusiv rocks cut one another in a most intricate manner. Many of the intrusivs, moreover, have been deformd and metamorphosed. On account of the complexity of the structure thus produced, the ordinary methods of stratigraphic and structural work can be applied only

[1] Local stratigraphic sections and other detaild information will be found in Chapter IV, Orographic Elements.

The U. S. Geological Survey has now in preparation (1912) a professional paper by Mr. B. Willis describing the formations of North America in their local details. When publisht this will be a store-house of information with reference to the stratigraphy of the United States.

Fig. 2. Generalized geologic map of the United States. (Adapted after Willis.)

in small and particularly favorable areas, and it is not yet possible to separate the system into divisions which can be correlated from place to place.

In some districts the Archeozoic can be definitly separated from the Proterozoic group by a visible unconformity, and by the conspicuous change in the character of the rocks. In New England, the Pacific Mountains, and some other districts, however, the later systems have themselves been so highly metamorphosed that it is generally impracticable to distinguish the Archean with certainty. At present it is therefore necessary to class many of the ancient rocks simply as pre-Cambrian.

The Archean system is well exposed and has been most thoroly studied in the Lake Superior highlands. It is also exposed, tho often difficult to recognize, in the Atlantic states, in the cores of the Rocky Mountain ranges, and in some of the deep canyons in the western plateaus. It has not yet been possible to differentiate rocks of great age in the Pacific Mountain system.

Local Characteristics.

Lake Superior Region. The pre-Cambrian rocks in the vicinity of Lake Superior are readily divisible into two large groups. The younger (Algonkian) system consists largely of sedimentary rocks in which the ordinary stratigraphic methods of work may be used. The older group (Archean) is dominantly of igneous origin and is too complex to be separated into formations which may be recognized over considerable areas.

On the north shore of Lake Superior, where the Archean rocks are least metamorphosed, they consist of ellipsoidal greenstones and schists which evidently originated as basic lava flows. Small bodies of slate, jasper and iron ore are associated with the greenstones in such a way as to make it appear that they are interbedded with the flows. On the south shore of the lake the prevailing rocks are green schists, the origin of which is not readily determinable. In both regions the greenstones are cut by granitoid and other intrusivs, many of which have since been altered into gneisses. Nearly all have been so much folded and metamorphosed that the relations between the different formations are highly complex.

Eastern Mountains. Along the eastern slope of the Appalachian Mountains from Alabama to New England, ancient metamorphic rocks are exposed in a nearly continuous band. Some of these rocks are known to be of Paleozoic age. Others are probably Proterozoic. Archeozoic rocks are doubtless widely distributed in this district, but since it is rarely possible to identify the younger strata positivly, it is difficult to distinguish the Archean system. In North Carolina and adjacent regions, the oldest distinguishable formations are gneisses (Carolina and Roan), parts of which are evidently sedimentary. These are cut by gneissoid granites and other igneous rocks.

In Maryland and adjacent states the Baltimore gneiss seems to be the equivalent of the Carolina gneiss farther south. It has similar associations.

The existence of Archeozoic rocks in New England and the Adirondack Mountains is suspected, but they are not yet discriminated from the Proterozoic.

Grand Canyon Region, Arizona. In cutting its remarkable canyon the Colorado river has trencht thru the prevailing sedimentary rocks and exposed an ancient formation which is generally referred to the Archeozoic complex. The rocks consist of intricately folded gneisses and schists which have been invaded by granites and other igneous rocks. They lie unconformably beneath unaltered sedimentary rocks of late Proterozoic age.

Other Western Exposures. Among the mountains of the western states, there are many outcrops of ancient metamorphic rocks. In some places they underlie Paleozoic beds and elsewhere are found beneath late Proterozoic sediments. Those in

the Rocky Mountains are clearly all pre-Cambrian in age and generally are older than the Belt terrane (Proterozoic). Those on the Pacific slope are in part Paleozoic or even Mesozoic, and it has not yet been possible to confidently distinguish pre-Cambrian rocks among them, if present. In the plateau region between the two mountain systems, the metamorphic rocks are probably largely pre-Cambrian. Some of these ancient rocks are doubtless of Archean age, but in the absence of a full sequence of Proterozoic strata in the West it is not yet possible to correlate definitly any of the rocks with the Archean complex of the eastern states.

Proterozoic.

General Characteristics.

The great sequence of formations which in some districts separates the Archean complex from the oldest fossiliferous rocks bears the name Proterozoic group (Algonkian system). The rocks are dominantly sedimentary and may be divided into several local systems. These are further sub-divided into formations which may be traced over considerable areas. In some districts the entire group seems to consist of sedimentary deposits. Elsewhere only igneous rocks seem to represent the Proterozoic. In still other regions ancient lava flows and intrusions are associated with the sedimentary rocks in varying proportions.

In a few places the Proterozoic rocks still lie in their original horizontal attitude, and altho consolidated are scarcely altered. In other districts they have been so highly folded and metamorphosed that to elucidate their structure and relations is difficult, if not impossible. On the average, however, they have been less folded and metamorphosed than the Archeozoic rocks which lie beneath them.

The Proterozoic rocks are usually found associated with the Archean. In many places the younger system occupies deep synclines in the older. In the northwestern mountains, however, there are considerable areas in which Proterozoic sedimentary rocks are widely exposed without interruption.

Local Characteristics.

Lake Superior District. In no part of the United States are the Proterozoic rocks so well known as around the borders of Lake Superior. They are found generally in complex synclines folded down into the Archean base. In some parts of the district the entire group has been divided into four systems which are separated from each other, from the Archean below, and from the Cambrian above, by well markt unconformities. The divisions are, however, somewhat local in their application. For example, in the Mesabi district of Minnesota, only three divisions are recognized and in the Crystal Falls region in northern Michigan, only two.

In an earlier classification two grand divisions were establisht, the Huronian and Keweenawan systems. The second division is still retained, while the first has been sub-divided in some places into two systems and in other places into three.

In the Marquette district on the south shore of Lake Superior, the lower Huronian rocks consist of the Mesnard quartzite, lying unconformably upon Archean greenstone and granite, followed by the Kona dolomite and Wewe slate,—all highly folded and locally somewhat metamorphosed. In the Penokee district, farther west, similar formations occupy the same relativ positions. In the Mesabi and Vermilion districts the lower Huronian rocks consist of conglomerate, quartzite, and slate, resting upon the Archean greenstone. They have been intensely folded.

The middle Huronian system is definitly recognized only in the Marquette district and along the north shore of Lake Huron. In the first named region it comprises the Ajibik quartzite and the Siamo slate, followed by jaspery iron formation (the

Negaunee). The bedding of the quartzite is nearly parallel with that of the underlying lower Huronian, but, by careful mapping, the existence of an obscure but important unconformity has been establisht.

The upper Huronian series in the Marquette district is separated from the underlying rocks by a definit but inconspicuous unconformity. At the base lies the Goodrich quartzite. This is overlain by the Bijiki schist with deposits of iron ore. Above these two relativly thin formations there lies a vast thickness of slates (Michigamme) with much extrusiv volcanic material interbedded. Farther south near the Menominee River the upper Huronian series is considerably metamorphosed and is intruded by granitic bosses.

Northwest of Lake Superior, in the Mesabi district, the gently inclined upper Huronian lies across the edges of the upturned and eroded lower Huronian and older rocks. The succession comprises the Pokegama quartzite at the base, followed by the iron-bearing formation and the thick Virginia slates. Northeast of the Mesabi district the upper Huronian system is represented by the Animikie beds of the Canadian shore of Lake Superior. In the opposit direction the upper Huronian beds have been traced by deep drilling, into central Minnesota, where they are much more highly folded and metamorphosed, and are intruded by large masses of gabbro and granite. In the Cuyuna mining district, therefore, the system is represented by highly folded slate with thin beds of quartzite and hard iron formation.

The youngest of the systems recognized in the Lake Superior region has been named the Keweenawan, from the peninsula on the south side of Lake Superior. It is found not only along the entire length of that peninsula, but in Isle Royale and as far southwest as eastern Minnesota. Northward it extends into Canada. The Keweenawan system consists largely of basic lava flows and coarse reddish sandstones and conglomerates. In the original locality the lavas succeed one another from the base upward without interruption to a vertical thickness of thousands of meters. At higher horizons conglomerates are intercalated between them, and near the top of the system the conglomerates and red sandstones predominate to the exclusion of the lava flows. From the scoriaceous surfaces of the lava sheets it is evident that they were terrestrial flows. The composition and red color of the sediments likewise suggest that they were accumulated on land. With the basic flows are associated occasional acidic lavas. There are also local intrusions of gabbro and many dikes of diabase.

In Minnesota the basal portion of the Keweenawan is generally sandstone and conglomerate and there are fewer flows than on the south shore of Lake Superior. South of the Mesabi district, the Duluth gabbro, a great laccolith or sill, is thought to be related to the Keweenawan lavas farther south.

Arizona. In the Grand Canyon of the Colorado River Proterozoic rocks lie between the Archeozoic and Paleozoic groups. Two very distinct systems have been referred to the Algonkian; one is called the Vishnu and the other the Grand Canyon system. According to Walcott, the Vishnu system consists of mica-schist and quartzite with intrusiv granite, but Ransome[1] regards it as all of igneous origin and probably Archean. The latter view is generally accepted.

The Grand Canyon system is unmetamorphosed and but slightly folded, and is separated from the older rocks by a conspicuous unconformity. Since its deposition it has been gently inclined and the entire sequence was later bevelled off, so that the Middle Cambrian sandstone rests horizontally upon the eroded edges of the Algonkian.

An erosion unconformity divides the Grand Canyon system into two series,—the Unkar and the Chuar. The Unkar series, about 2200 meters thick, consists of hard sandstone, shale, and cherty limestone, with some conglomerate at the base

[1] Ransome, F. L., Abtsract in Science, N. S. XXVII, p. 68, 1908.

and a few volcanic flows and intrusions at higher horizons. Many of the sandy beds are ripple-markt, and sun-cracks have been found in the shales. Altho the rocks are not appreciably altered, no identifiable fossils have as yet been discovered in them.

The Chuar series, 1600 meters thick, comprises shale with a small amount of limestone. In the lower part of this series Walcott has found a few doubtful fossils thought to be primitiv brachiopods and pteropods.

In central and southern Arizona, schist, quartzite and other altered sediments have generally been referred to the Archean. Ransome[1], however, favors the view that they are equivalent to the Grand Canyon series.

Idaho and Western Montana. In the northern Rocky Mountains Proterozoic rocks have a wide distribution, and similar formations appear beneath older rocks at many points in Wyoming, Colorado and Utah. In Montana the Cherry Creek series is believed to be of early Proterozoic age. It consists of marble, mica-schist and quartz-schist. These are obviously sedimentary rocks, but they have been intensely folded and metamorphosed. The distribution of the system at the surface seems to be small and its relations to the Archeozoic and the later Proterozoic formations doubtful.

A younger system comparable lithologically to the Grand Canyon series is widespread. The name Belt system is applied to these rocks in Montana, and similar formations in adjacent regions are correlated with it. The Belt system generally rests upon gneiss and schist which are referred to the Archean complex. Its upper limit in southern Montana is an unconformity which separates it from the middle Cambrian sandstone. The Belt system consists of quartzite, massiv argillite, dolomitic limestone, and shale. The total thickness is at least 3000 meters. The formations are coarser and contain much conglomerate in northwestern Montana and Idaho. In Idaho, particularly, many of the quartzites have ripple-markt bedding planes. In Montana poorly preserved fossils have been found in two localities. The best known form is *Beltina danai*, which was apparently a eurypterid.

Like the Grand Canyon system the Belt strata are but little altered and only moderately folded. The folding becomes stronger westward, but the Paleozoic rocks are deformed to the same degree. In Montana the Belt system was slightly folded and eroded before the middle Cambrian rocks were deposited.

Colorado and Utah. In several ranges of Colorado and Utah, the pre-Cambrian rocks may be definitly separated into two or more systems. In southwestern Colorado there is a complex of ancient greenstones with which are associated layers of altered quartzite. Upon these rocks rests unconformably a much younger series of quartzite and dark slates called the Uncompaghre formation. The quartzites contain seams of fine conglomerate at many horizons. Into all of the pre-Cambrian formations has been intruded a granite which appears to be the youngest Proterozoic rock of the district. The quartzites are moderately and, in some places, strongly folded, but are not much altered. On the eroded edges of the strata rest beds of Cambrian and Devonian age.

In the Wasatch and Uinta ranges of Utah, two ancient systems are again known. The oldest rocks (assigned to the Archean) are highly metamorphosed and seem to be largely of igneous origin. Upon these rests a succession of quartzites and slates which is estimated to be about 3500 meters thick. Near Salt Lake this quartzite-slate formation is separated by an obscure unconformity from a younger quartzite overlain by shales which carry Lower Cambrian fossils. The division from the Cambrian is still unrecognized in the adjacent districts. Like the Paleozoic beds, the Proterozoic rocks are now moderately folded but have been scarcely metamorphosed. In the Uinta range the so-called Red Creek quartzite, a schistose formation beneath the unaltered quartzite-slate series, may be an older Algonkian terrane.

[1] Loc. cit.

It thus appears that thruout the Rocky Mountains there is a widespread system of quartzites and slates resting unconformably on ancient metamorphic rocks and usually unconformably beneath Paleozoic strata. It is now thought that all of these terranes are of late Proterozoic age, and that the Grand Canyon series may be correlated with the Belt system of Montana and Idaho thru the intermediate formations in Colorado, Utah and Wyoming. eastern

In Nevada and even in western California thick formations, chiefly quartzitic, have been found beneath the Olenellus zone, in isolated mountain ranges. These rocks have yielded no fossils and altho closely related to the Cambrian are generally classed as Algonkian.

Black Hills. Pre-Cambrian rocks are exposed in the central part of the Black Hills of South Dakota. The oldest appear to be slates, with which are associated beds of quartzite, conglomerate and ferruginous chert. These are highly folded in a north-south direction and are cut by secondary cleavage planes which are usually not parallel to the bedding. The rocks bear a close resemblance to some of the slaty formations found in the upper Huronian of Minnesota. The slates have been invaded by batholitic intrusions of granite, now surrounded by broad contact zones within which the slaty series has been changed to schists. During metamorphism all the original structures have been obliterated and the schistosity is generally parallel to the boundaries of the intrusion.

On the deeply eroded surface of the pre-Cambrian rocks rests the late Cambrian sandstone.

Texas. In central Texas a window-like opening in the Paleozoic cover exposes a complex of pre-Cambrian rocks. From the recent studies by Paige[1], it is known that a highly variable schistose series is intruded by granite and more basic plutonic rocks. The metamorphic complex, called the Llano series, consists of light colored acid gneiss with marble, apparently overlain by schistose basic volcanic rocks with interlaminated marble, graphite schist and other derivatives of sedimentary rocks. The rocks are highly folded in a generally northwest-southeast direction, but are much broken by subsequent intrusions. On the deeply eroded surface of the entire pre-Cambrian mass rest the sedimentary rocks of Cambrian and later age.

Southeastern Mountains. Altho pre-Cambrian rocks, of which some are doubtless Proterozoic, are exposed in many parts of the eastern mountain system, there are but few places in which the pre-Cambrian rocks have been subdivided. In Alabama and the Carolinas there is a system of sedimentary rocks of vast thickness the upper part of which contains lower Cambrian fossils. At the base, the system rests unconformably on metamorphosed rocks, largely of igneous origin. This great thickness of folded sedimentary beds generally bears the name Ocoee series. The Olenellus fauna has been found in the upper part of this system but no trace of fossils has been discovered in the lower, altho there are limestones and shales in which animal remains might be expected. According to Walcott's classification, the lower part of the Ocoee series therefore is to be regarded as late Proterozoic; but Keith considers it all Cambrian. The difference is due merely to point of view.

Undivided pre-Cambrian.

General Characteristics.

In many parts of the United States there are ancient rocks, in some places known to be older than the Cambrian and in other places thought to be so, which can not

[1] Paige, S., Mineral resources of the Llano-Burnet region, Texas, U. S. Geol. Surv. Bull. 450, 1911.

be referred confidently to either Archeozoic or Proterozoic groups. This is especially true of the New England region, the Appalachian Mountains and the Pacific slope. In the interior of the country there are other localities where the pre-Cambrian formations are all igneous and hence not easily separated into two systems. On the borders of the continent the difficulty of discriminating two groups of pre-Cambrian rocks arises chiefly from the intense metamorphism to which not only ancient but even younger formations have been subjected.

Local Characteristics.

New England and Adjacent Regions. In the northeastern part of the Atlantic mountain system, particularly in New England, the igneous rocks, both metamorphic, and unaltered prevail. Some of the formations are known to be of Paleozoic age, but a part is certainly pre-Cambrian. The pre-Cambrian rocks are best known in southwestern New England, the Adirondack region and northern New Jersey. There they consist chiefly of gneiss and schist, associated with considerable bodies of crystalline limestone. Beds of valuable magnetite and other ores are found in them.

The stratified formations have been folded and comprest into isoclinal structure, in which the prevailing dips seem to be southeasterly. Some of the rocks are demonstrably of sedimentary origin, while the original condition of others is doubtful. Into all the formations have been intruded many kinds of igneous rocks, chiefly granite and gabbro in the form of batholiths, and many others as smaller intrusions. Some of the intrusives have themselves been rendered schistose at a later time. The entire complex is separated by an unconformity from the Lower Cambrian formations which are infolded with them. The pre-Cambrian sedimentary rocks bear a close resemblance to the Grenville series of eastern Canada and are believed to be equivalent to it. Since the age of the latter is still in doubt, however, the formations in eastern United States can not yet be referred to either Archean or Algonkian.

Southeastern Mountain Region. In the low Piedmont plateau and in the mountains of the Carolinas and adjacent states, pre-Cambrian rocks are prevalent. The formation believed to be oldest is a gneiss of complex constitution. It contains small bodies of limestone and other rocks doubtless of sedimentary origin. This formation is called the Carolina gneiss in the southern part of the region and the Baltimore gneiss farther north. Many younger formations are found in different parts of the region. In eastern Pennsylvania there are altered rhyolites and basaltic breccias and tuffs which lie unconformably beneath the Lower Cambrian. In the Carolina region there are similar extrusiv igneous rocks and also slates and siliceous dolomites. It is not certain, however, that some of these are not of Paleozoic age. Into the gneisses and schists have been intruded granites and other igneous rocks of several generations, and of these many have since been changed to gneiss. In all of them the present structures have a general northeasterly trend and are largely of secondary origin.

Missouri. In a small exposure of pre-Cambrian rocks in southeastern Missouri, two systems appear to be distinguishable. The older consists of granite and porphyry with later basic dikes, while the younger consists of iron ore and conglomerate derived from the igneous rocks. The iron-bearing formation is said to resemble rather closely some of the iron-bearing formations of the Lake Superior Algonkian. All of the pre-Cambrian rocks are covered unconformably by Cambrian and later sediments which rest upon them horizontally.

Oklahoma. In southern Oklahoma pre-Cambrian rocks are exposed in the Arbuckle and Wichita mountain groups. The rocks are all of igneous origin and consist chiefly of granite with small bodies of porphyry, gabbro and aporhyolite. All

of these are covered by a middle Cambrian sandstone which contains fragments of the pre-Cambrian rocks.

Western Mountains. In addition to the pre-Cambrian rocks which have been described above, under the headings "Archeozoic" and "Proterozoic", there are many others of which it is safe to say only that they are pre-Cambrian, or in some cases merely that they are very old. In the cores of many ranges from Montana south to New Mexico and Arizona, there are metamorphic rocks of unknown origin associated with various kinds of altered and unaltered igneous rocks. Upon them rest unaltered strata which are generally either Cambrian or late Proterozoic. Future study may result in the subdivision of these rocks into distinct formations, some of which may be referred to the Algonkian and others to the Archean. In the Pacific ranges and adjacent portions of Washington, Oregon and Nevada there are ancient metamorphic rocks of which the age is doubtful. In some places they are known to be older than the Carboniferous and in others older than the Devonian, but at present little information about them is available.

Paleozoic Group in General.

The Paleozoic rocks are widely exposed thruout the interior of the United States, but have not been certainly identified anywhere along the shores of the Pacific Ocean and Gulf of Mexico, and nowhere on the Atlantic coast except in New England. In the great interior lowlands they usually lie flat and are relatively unaltered. In the mountain systems near the east and West borders of the continent they are much folded. In the Sierra-Cascade mountains of the West, they are generally much metamorphosed, while in the Appalachian Mountains they are notably disturbed but only locally metamorphosed. In the Rocky Mountain system they are but moderately folded and not notably altered, except in the vicinity of igneous intrusions.

The Paleozoic group of rocks is many thousands of feet thick in the Appalachian Mountains, in the western plateau region, and probably in the Pacific ranges. Thruout the interior, except in Arkansas and Oklahoma, the group is much thinner—generally less than 1000 meters thick.

All of the Paleozoic systems from the Cambrian to the Permian are represented in the United States; but they are not all equally widespread nor equally well developt where exposed. Excepting a small area along the Ohio river, the Permian system is confined to the western part of the United States, and over much of the region the rocks are not marine. For the earlier systems the sections in New York and adjacent states are generally used as the standard. This is not true, however, for either the Permian or the Mississippian system.

Cambrian.

General.

Lithology. The Cambrian system in the United States consists almost exclusivly of sedimentary rocks, and among these the sandy sediments predominate. It is true that there are large bodies of shale and slate in some localities and, in the Appalachian Mountain system and Basin Ranges, there is much limestone in the upper horizons. Scarcely any volcanic rocks of proved Cambrian age have been discovered in this country.

There is great variation in the thickness of the system in different places. In the interior lowlands and the Rocky Mountains the Cambrian strata are generally less than 300 meters thick. In the southern Appalachian Mountains, however, and in the northwestern plateau region, the system is represented by very massiv strata with a maximum recorded thickness of about 4,000 meters.

Subdivisions. It is customary in the United States to divide the Cambrian system according to C. D. WALCOTT into three series, as follows:

Upper Cambrian	. . . . .	Saratogian (or Potsdam)
Middle „	. . . . .	Acadian
Lower „	. . . . .	Georgian

These series were originally identified in the northeastern part of the United States, but formations farther west are now correlated with them by means of abundant fossils.

Distribution. Altho the Cambrian formations underlie the greater part of the United States, they are now exposed at the surface in rather small areas. The Cambrian outcrop skirts the patches of pre-Cambrian rocks in the northeastern and eastern highlands of the United States. They are found in isolated uplifts in Missouri, Oklahoma and Texas. They are also exposed in narrow bands around the cores of many of the Rocky Mountain ranges and at many scattered places in the Basin Ranges. The Cambrian system has not yet been identified in the Pacific system of mountains, altho it is known in southeastern California along the western edge of the plateau region.

The Georgian series is the most restricted of the three, for it is found only in the Appalachian Mountains and in the western plateau region. The middle Cambrian or Acadian series is prevalent in the Rocky Mountains and in the south central interior as well as in the far east and west. The upper Cambrian or Saratogian series is much more widespread than either of the others. Originally it probably covered all of the United States, with the possible exception of some isolated islands.

Local Characteristics.

Nevada Region. In Nevada, Utah and adjacent states the Cambrian system is represented by a thick succession of sediments which contain Georgian, Acadian and Saratogian faunas. In some parts of this region the base of the system is not exposed but in others the fossiliferous Cambrian rocks rest without observed unconformity upon a thick series of quartzite and slate, which are usually referred to the Proterozoic. In Inyo County, California, the shales which contain the sub-*Olenellus (Nevadia weeksi)* fauna rest conformably upon a thick limestone formation, which, under the prevailing arbitrary rule, would seem to be referable to the pre-Cambrian.

In the Cambrian system, as thus limited, the rocks are chiefly limestone with interbedded shales or slates.

Southern Appalachian Province. Here, as in the far west, the base of the Cambrian system is indefinite. The oldest rocks which contain the *Olenellus* fauna lie conformably upon the thick series of clastic sedimentary rocks which form part of the Ocoee series. On a previous page the Ocoee series has been referred to the Proterozoic, but A. KEITH argues plausibly that, since it is continuous with the fossiliferous Cambrian beds, the entire sequence, from the unconformity at the base of the Ocoee to the horizon of Ordovician fossils, should be called Cambrian.

The Cambrian rocks of the southern Appalachians consist chiefly of slate, conglomerate and quartzite, passing into limestone above. The rocks are now highly folded and have been somewhat metamorphosed in the process. The maximum thickness of the beds, measured from the basal unconformity, is said to be more than 3000 meters.

New England Province. In New England and immediately adjoining parts of New York the Cambrian rocks are generally not only highly folded but metamorphosed. Locally, however, they have been found in sufficiently unaltered condition so that the fossils in them have not been obliterated.

Near Boston small patches of Cambrian rocks have been found in several places. Thus, at North Attelboro, Mass., there is a body of slate and limestone which contains lower

Cambrian fossils; and at Braintree a few miles distant, dark slates containing the *Paradoxides* fauna, of middle Cambrian age, are infolded with the older rocks. In neither place are the relations well known.

In western Vermont the Cambrian is represented by a succession of shales or slates with many bands of limestone and a little quartzite. The entire sequence is more than 3000 meters thick and contains fossils of lower, middle, and upper Cambrian age. The rocks are highly folded and somewhat metamorphosed. The metamorphism becomes more intense eastward and southward.

In southwestern New England and in the Hudson river valley in New York, the Cambrian rocks comprise schist, gneiss, and marble. The marble, generally known as the Stockbridge limestone, is thought to correspond to the Kittatinny limestone and Knox dolomite farther southwest, and these are known to be partly of late Cambrian age. These metamorphosed Cambrian rocks are associated with Ordovician beds and both lie unconformably beneath the Silurian.

Rocky Mountain Region. In passing from the Basin Ranges eastward to the Rocky Mountains the Cambrian system suffers a great diminution in thickness, and the lower part of the system is not represented. The middle Cambrian is usually sandstone or quartzite while the upper Cambrian is shale with some limestone and a peculiar limestone conglomerate. The average thickness of the system is but a few hundred meters, and in many places it is less than 50 meters. The base is often conglomeratic and always rests unconformably upon pre-Cambrian rocks. In most parts of the Rocky Mountains the Cambrian passes conformably upward into Ordovician limestone but in parts of Colorado and Arizona the limestone is lacking and much younger formations rest unconformably upon the Cambrian.

The Rocky Mountain phase of the Cambrian system is found also in certain outlying districts east and southeast. In central Texas it consists of brown sandstone with interbedded limestone. In Oklahoma there is a thin middle Cambrian sandstone followed by a thick mass of limestone the upper part of which is of Ordovician age.

Great Lake Region. In the states bordering the Great Lakes the Cambrian system resembles that of the Rocky Mountains more closely than any other. The greater part of the system is sandstone, but in the upper portions there are usually beds of shale and limestone. These are of local distribution, however, and vary from place to place. The limestone increases in thickness as the beds are traced southward toward Missouri. The sandstone with its local shales and limestones contains fossils of upper Cambrian age, and at some points in Minnesota and Missouri the lowest faunas are thought to be middle Cambrian. In the older reports the entire formation has been called the Potsdam sandstone. It is now subdivided into local formations but the names are not widely used.

Certain reddish sandstones on the south shore of Lake Superior have been thought to belong to the Cambrian system. They lie horizontally upon the folded pre-Cambrian rocks but have as yet yielded no fossils. It is probable that they belong to the Keweenawan system, which is usually assigned to the late Algonkian. It may be noted here that, contrary to general usage, the entire Keweenawan series is referred to the Cambrian system by A. C. Lane and some other geologists of Michigan.

The Cambrian rocks of the Lake Region are almost everywhere nearly horizontal. They pass beneath younger strata southward and appear to underlie almost all of the great interior lowland. In these northeastern states the formation is generally less than 400 meters thick.

Ordovician (Lower Silurian).

General.

Lithology. In the United States the Ordovician system probably contains more limestone than any other. In some parts of the country, particularly in the West, it is all limestone. In the East there are notable thicknesses of shale, chiefly of late Ordovician age, but even there thick limestone formations are associated with the clastic rocks.

Like the Cambrian system, the Ordovician rocks are thickest in the Appalachian mountains and in the western plateau region, but are thinner in the interior lowlands. As an exception to this general rule, however, it may be noted that in Oklahoma and Arkansas the early Ordovician rocks are 1000—2000 meters thick.

Subdivisions. The standard section of reference for the American Ordovician system is that of central New York, for in that region the rocks contain many fossils and have been well studied. The older section by James Hall has been widely used for many years, but in the last decade several new classifications have been suggested, and in 1910 C. Schuchert[1] even proposed to divide the system into three of full system rank. The New York divisions are not easily applied southwest and west, altho correlations are being gradually extended. In the western mountains it is much more difficult to recognize the eastern divisions.

Distribution. The outcrops of the Ordovician system usually lie just outside of and parallel to those of the Cambrian. In addition the Ordovician rocks are found in the Cincinnati and Nashville uplifts in the eastern interior, where the Cambrian rocks are not exposed, and in northern Michigan, where the Cambrian is missing. On the other hand there are a few localities, as in parts of Colorado, where the Cambrian is found without the Ordovician.

Local Occurrence.

Lake Region. In New York a three-fold division of the Ordovician system has generally been made. The lower consists of the Beekmantown limestone, which is represented in Wisconsin by the Lower Magnesian limestone. This is usually separated by an obscure erosion unconformity from the middle Ordovician sandstone and limestone, while the middle rests conformably beneath upper Ordovician limestone and shale. The formations vary from place to place and are differently grouped by individual stratigraphers. Westward along the northern edge of the system the formations become somewhat thinner but preserve the same general relations. In northern Michigan the middle Ordovician beds overlap the Cambrian and rest upon the folded pre-Cambrian rocks.

Appalachian Mountains. Ordovician rocks extend the entire length of the Appalachian Mountains, and, being highly folded, they outcrop in narrow bands parallel to the strike. The lower part of the system is usually a thick limestone which is merely a continuation of the Cambrian limestone. This great Cambro-Ordovician formation is called the Kittatiny limestone in New Jersey, the Shenandoah limestone in Maryland and Virginia, and the Knox dolomite farther southwestward. The older limestone is generally followed by a middle Ordovician limestone, and the two are separated locally by a slight unconformity. Upper Ordovician shales, followed in the central Appalachians by sandstone, complete the section. In this region the system is 600 to 1500 meters thick.

New England Province. Like the Cambrian rocks of this region the Ordovician formations are highly folded and in most places intensely metamorphosed.

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[1] Schuchert, Chas., Paleogeography of North America. Geol. Soc. of Am., Bull. XX, 1910, pp. 427—606.

On the eastern coast (Maine) crystalline limestone associated with quartzite and schist are separated by an unconformity from fossiliferous Silurian rocks. They are believed to correspond to the Ordovician limestones of the eastern interior region.

Along the western side of New England and extending down thru New Jersey and Maryland, at least as far as southern Virginia, there are other metamorphosed strata in which at a few points deformed Ordovician fossils have been found. The most conspicuous and best known formation is the Stockbridge limestone of western New England and eastern New York. This appears to be roughly equivalent to the Shenandoah limestone or Knox dolomite. In central Massachusetts a mass of schists and amphibolites which lies unconformably beneath the Silurian is referred by EMERSON[1] to the Ordovician.

Southern Interior Region. Ordovician rocks are widely distributed from Tennessee and southern Missouri south and southwestward to central Texas. In central Tennessee not all of the system is exposed, but that which is visible consists of limestone which is shaly at certain horizons and locally phosphatic. In this locality ULRICH notes the presence of several obscure unconformities within and at the top of the system. In the Ozark and Boston Mountains of Missouri and Arkansas respectivly, the rocks are limestone with beds of sandstone and shale. The most persistent formations appear to be those of lower Ordovician age. The middle Ordovician seems to be lacking and even the upper is not always present.

In Oklahoma a very thick limestone (the Ozarkian of ULRICH[2]) which contains upper Cambrian fossils below and early Ordovician fossils above, is followed by limestone with alternate beds of shale and sandstone, in which middle and upper Ordovician fossils have been found. The system here seems to be conformable beneath the Silurian, altho this is not the usual relation in the eastern half of the United States.

In central Texas the Burnet limestone is Cambro-Ordovician. It is less than 100 meters thick and is limited above by an obscure unconformity.

Utah and Nevada. The Ordovician formations of Nevada are the Pogonip limestone (600—1000 meters) and the Eureka quartzite (150—300 meters). The quartzite is separated by an unconformity from the Lone Mountain limestone which contains both late Ordovician and perhaps Silurian fossils. In Utah the Ordovician period is represented by only a portion of a thick succession of limestones which contains Cambrian fossils below and later Paleozoic faunas above. Some green shale and quartzite form a part of the Ordovician.

Rocky Mountains and southwestern plateaus. Thruout this vast region the Ordovician rocks are rather thin, and locally they disappear entirely. In western Montana a limestone, usually destitute of fossils, represents the entire system. There, as in Utah, the sequence from Cambrian to late Paleozoic is essentially conformable. A yellow dolomite with early and late Ordovician fossils is widespread in Wyoming, and extends east to the Black Hills; but it is entirely absent in southeastern Wyoming and northern Colorado. It reappears as a basal sandstone and thin dolomitic limestone apparently of middle Ordovician age in central and southern Colorado, but in southwestern Colorado and adjacent districts it is again missing. In southern New Mexico and western Texas, Ordovician fossils are found, as in Montana, in a thick limestone which ranges in age from Cambrian to Carboniferous. In these sections fossils are generally scarce, and the faunas have been but imperfectly correlated with the standard sections of eastern United States.

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[1] EMERSON, B. K., Geology of Old Hampshire County, Mass., comprising Franklin, Hampshire, and Hampden Counties. U. S. Geol. Survey, Mon. 29, 1898.

[2] ULRICH, E. O., Revision of the Paleozoic Systems in North America. Abstract: Science, new ser., vol. 29, p. 630, 1909.

Silurian (upper Silurian or Gothlandian).

General.

Like the Ordovician system, the Silurian rocks of the United States consist largely of limestone, altho clastic sediments are prominent in the East. The system is best known in the eastern interior region, in the vicinity of the Great Lakes. For many years it was believed that the Silurian system was but poorly represented in the western plateaus and mountains, but recently it has been found to be widely distributed, altho poor in fossils. It consists largely of barren dolomite.

For many years the standard section of reference was that of New York, but more recently a composite section from New York and Michigan has been used.

Local Occurrence.

Northeastern Lake Region. The Silurian rocks of New York state and vicinity consist generally of sandstone with local conglomerate at the base, followed by shale and limestone, then by salt-bearing shale and dolomite, and finally by more limestone. The uppermost strata are closely related to the Devonian system and appear to grade into them conformably except near Hudson River. At the base of the Silurian the coarse clastic deposits lie discordantly upon the older rocks in eastern New York, but the homotaxial shales are scarcely separable from the Ordovician strata in central New York, Pennsylvania, and westward.

The old and familiar section of the New York Silurian rocks begins with the Oneida conglomerate at the base, followed by the Medina formation,—a thick succession of brown and white sandstones. The Clinton formation consists largely of shale with fossiliferous limestone and local deposits of hematite iron ore. The succeeding Niagara limestone, containing an abundant marine fauna, is about 70 meters thick in New York but increases westward, until in northern Illinois it is 120 meters thick and fills the entire section from the Ordovician shale to the unconformity at the base of the Devonian. The Niagara limestone series is succeeded in the Erie-Ontario region by reddish shales which contain beds of salt, gypsum and dolomite. These are in turn followed by a fresh water limestone and associated gray shales. The section is completed by a thin series of limestones which were not at first clearly distinguisht from the overlying Devonian beds. These are now known to be equivalent to the better developt Monroe series of Michigan, which consists of limestone and sandstone containing Silurian faunas with strong Devonian affinities.

All of the coarser clastic formations in the Northeast become rapidly thinner westward and pass into shale or disappear before the Mississippi River is reached. It is now believed that the formation formerly called the Oneida conglomerate is of various ages in different parts of the region, being equivalent to the Medina sandstone in central New York and Pennsylvania but in New Jersey contemporaneous with younger beds.

New England Region. Owing to the complexity of structure among the Paleozoic rocks in New England the various systems have been identified in only a few places. Fossiliferous Silurian slates have been detected on the coast of Maine. They carry a fauna which appears to be homotaxial with that of the Niagara and Clinton formations of the eastern interior.

In west-central Massachusetts B. K. Emerson[1] refers a highly folded series of schists and slates to the Silurian system. They are notably less metamorphosed than the Ordovician rocks upon which they rest unconformably. Like them, however, they are intruded by granites and other igneous rocks.

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[1] Op. cit.

Southern Appalachian Mountains. When traced southwestward from New York along the Appalachian Mountains the Silurian formations become thinner. In Maryland they are about 1000 meters thick, in western Tennessee about 500, and in Alabama 150 or less. The Oneida, Medina and other clastic formations of the New York section find their continuation in this district in a series of red, brown, and white sandstones and quartzites which have various local names, among which the best known are the Juniata and the Tuscarora formations. Southwestward these do not extend beyond Tennessee. Upon these sandstones rests an alternation of shale and sandstone with some beds of limestone and fossiliferous iron ore, best known as the Rockwood formation and comparable to the Clinton beds of New York. In the southern part of the Appalachian mountains this formation rests unconformably upon Ordovician rocks. From Maryland to Tennessee the upper part of the Silurian system contains a variable thickness of limestone (Lewistown) which corresponds to the Niagara, Salina, and Monroe beds of the Lake region. This limestone disappears southwestward, however, and seems to be represented by an unconformity south of Tennessee. The uppermost limestones usually merge into the basal Devonian limestone, but in the southern part of the district the late Devonian shale rests unconformably upon the early Silurian Rockwood formation.

Central Interior Region. Traced westward from the Appalachian Mountains the Silurian beds disappear beneath Devonian and Carboniferous strata, but re-appear again in central Tennessee, Kentucky, Ohio, and the lower Mississippi valley. The system as there exposed consists largely of limestone with subordinate shale. In central Tennessee there is shale and limestone in which Ulrich[1] reports several minor unconformities. Only the Clinton and Niagara horizons of New York seem to be represented, and the total thickness is about 100 meters. In southern Illinois the Alexandrian limestone of Savage[2] lies conformably upon Ordovician shales and carries a fauna with distinctly Ordovician relationships. It appears to be separated by a slight unconformity from an overlying limestone which represents the Clinton of New York. The entire series is but little over 30 meters thick, and the later Silurian formations are represented by an unconformity separating the Silurian from the Devonian.

In the upper Mississippi valley states, Iowa, Illinois and Wisconsin, the Silurian system is somewhat thicker and consists almost entirely of limestone. It is usually conformable upon the Richmond shale (uppermost Ordovician), but it is almost everywhere separated by an unconformity from the overlying Devonian or Carboniferous beds. The Silurian limestone of these states is homotaxial with the Clinton and Niagara formations of New York. This limestone reaches a thickness of 250 meters in eastern Wisconsin, but in other localities has been reduced to much thinner proportions by post-Silurian erosion.

Southwestern Interior. In Oklahoma and Arkansas the Silurian system is everywhere comparativly thin and consists largely of limestone. In this respect it most resembles the system in Tennessee. In Arkansas the St. Clair limestone seems to be homotaxial with the Clinton. It rests conformably upon the Ordovician but is separated from the Devonian by an unconformity. The westward extension of these beds in Oklahoma is called the Hunton limestone. This rests upon the Sylvan shale which is regarded as transitional to the Ordovician system below. Silurian formations do not appear in the central Texas exposure of Paleozoic rocks, for the Carboniferous beds there rest on the eroded Ordovician.

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[1] Ulrich, E. O., Columbia, Tenn., folio (No. 95). Geol. Atlas of U. S., U. S. Geol. Survey, 1903.

[2] Savage, T. E., The Ordovician and Silurian formations in Alexander County, Illinois. Am. Jour. Sci., 4th ser., vol. 28, pp. 509—519, December, 1909.

Montana and the Basin Ranges. For many years it was supposed that the Silurian system was not represented in Montana, but recently Silurian fossils have been found in the southwestern part of the state and also in western Wyoming in a thin conformable sequence of limestone which represents most of the Paleozoic systems. Farther southwest in Nevada and the adjacent state of Utah, Silurian fossils have likewise been found in the midst of a thick limestone. At Eureka, Nevada, the limestone contains Ordovician fossils in its lower part and Silurian fossils above. It passes conformably upward into Devonian shale. In Nevada the Silurian portion of the limestone is probably more than 300 meters thick, and is thus contrasted with the Montana section where the Silurian beds are only 30—60 meters thick. In this region it has not been possible to separate the Silurian into faunal zones, nor to correlate the faunas closely with those of eastern United States.

Western Texas and New Mexico. A Silurian fauna has recently been discovered in the Paleozoic limestones in the mountains of southern New Mexico and the adjacent part of Texas.

Central Rocky Mountains. In Colorado, eastern Wyoming and the Black Hills of South Dakota, no Silurian formations have been identified. In many localities Devonian or Carboniferous strata rest unconformably upon Ordovician or older rocks, so that it is clear that the absence of the Silurian system, if a fact, is due either to non-deposition or to post-Silurian erosion. In some places the apparent absence may be due to the deficiency of fossils. This condition is extended southwestward into Arizona and northern Mexico, for at Bisbee and other points in Arizona the Devonian strata lie unconformably upon the Cambrian.

Pacific Mountains. In the highly folded rocks of the Sierra Nevada and other Pacific ranges the older Paleozoic systems have been identified in but few places. Silurian fossils have been found by Diller[1] in northeastern California in limestone associated with shale and sandstone, which in turn rests on bedded rhyolite flows. These are the oldest rocks of the Sierra Nevada of which the age has been determined. They are followed in apparent conformity by Devonian formations which are somewhat more widely known.

Devonian.

General.

The Devonian system in the United States contains less limestone than either the Ordovician or the Silurian. In eastern United States there is a large proportion of shale and sandstone, altho farther west, except in the Pacific region, limestone predominates.

The distribution of the outcrops is much the same as that of earlier systems. It is wanting, however, in parts of Illinois and Wisconsin where the older formations are found, and is present in the Colorado-Arizona region where the Silurian is absent. It is also more widely known in California and Oregon.

The faunas of the Devonian of the United States, especially those of the earlier epochs, are markedly provincial. The later faunas, especially of the West, are more cosmopolitan and are closely related to those of the Russian and Asiatic Devonian.

Local Occurrence.

Northern Appalachian Region. In the older reports on northeastern United States the Devonian system is usually subdivided into the Helderberg limestone (by some placed in the Silurian), the Oriskany sandstone, the Corniferous limestone, the

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[1] Diller, J. S., Geology of the Taylorsville region, California. U. S. Geol. Survey, Bull. 353, 1908, pp. 16—17.

Hamilton shale and the Chemung-Catskill sandstone and shale. Later studies have added details and increast the refinement of subdivisions.

The lowest Devonian formations consist largely of limestone with some shale, more than 100 meters thick. Upon the limestone rests a coarse sandstone (Oriskany) which is but a few meters thick in New York, altho it reaches a maximum thickness of 100 meters in Maryland. Thence southwestward, the Oriskany formation becomes thinner and less sandy. Unlike most sandstones, it is usually crowded with fossils, which are celebrated for their large size and coarse structure.

The middle Devonian series consists largely of limestone at the base and shale above. Eastward toward the Hudson River both of these formations grade into coarser clastic beds, the Onondaga (Corniferous) limestone being partially replaced by grits, and the overlying shales becoming much more sandy. The Onondaga limestone stretches westward as far as the Mississippi River and is noted for its wealth of corals, particularly those of solitary habit. The Marcellus and Hamilton shales are usually of dark color and often black. At many horizons they contain abundant fossils which have been thoroly studied by many paleontologists.

The upper Devonian formations are separated from those beneath because of a sudden change in the faunas. This change is usually ascribed to the entrance of the northwestern or Eurasian fauna into northeastern United States at the close of middle Devonian time. In western New York and Ohio the beds are rather thin and consist largely of shale with many marine fossils. In eastern New York and Pennsylvania, however, the series increases to a thickness of 700 to 1500 meters. It there consists of alternating reddish sandstones and sandy shales (Catskill beds), which are generally interpreted as continental sediments. Fossils are rare in these rocks; most of them are plants or fishes.

In New York the Devonian system either passes down conformably into the uppermost limestones of the Silurian or is separated from them by a minor unconformity. At its upper limit it likewise grades into the Mississippian formations, so that it is usually difficult to draw a dividing line between the two.

New England. Like all the Paleozoic rocks of New England, those of Devonian age are highly folded and more or less metamorphosed, except in favorable localities. For this reason the system is imperfectly known and has been identified in but few places. In central Massachusetts it consists of marble and schist resting unconformably upon Silurian schistose rocks. The marble contains a few fossils of Devonian age.

In central Maine lower Devonian limestone and slate with fossils have been identified. In southeastern Maine a series of conglomerates and sandstones interbedded with basic lava flows rests unconformably upon marine strata which are cut by intrusions of granite. The marine beds contain fossils which are either late Silurian or early Devonian, while the sandstones above have yielded plant remains which have a late Devonian aspect with Carboniferous affinities.

Southern Appalachian Mountains. The thick Devonian formations of the northern Appalachians dwindle to almost nothing in Tenessee, Georgia and Alabama. The lower and middle Devonian formations are usually absent and the period is represented only by the Chattanooga black shale. Altho but a few meters thick this formation is remarkably persistent over large areas. It contains only a few fossils, but these seem to be of upper Devonian age, altho Schuchert has recently assigned it to the early Mississippian.[1] At a few points in Georgia and Alabama a lower Devonian fauna homotaxial with that of the Oriskany sandstone, has been found in thin layers of chert which are separated from the overlying Chattanooga shale by a slight unconformity.

[1] Schuchert, Chas., Paleogeography of North America, Geol. Soc. of America, Bull. XX. 1910, pp. 427—606.

Central Interior Region. The Devonian system thins rapidly westward from the Appalachian Mountains until in Indiana it is but a few meters thick. Over considerable areas in northern Illinois and Wisconsin it is entirely lacking, altho there is evidence that a Devonian black shale once covered most of these states. In Iowa, thin limestone formations contain middle and upper Devonian fossils, and grade up into the Mississipian system. Farther south, in southern Illinois and central Tennessee, limestones contain lower Devonian fossils and locally upper Devonian, but are interrupted by local unconformities. In many places around the Ozark uplift the Devonian system is absent, but in others it is represented by beds a few meters thick. On the north slope of the plateau these consist of limestone with comparativly few fossils. On the south side, the Sylamore sandstone, which is correlated with the upper Devonian, rests unconformably upon older rocks and passes upward into the Mississippian system. As the Arkansas beds are traced westward into Oklahoma they pass into chert and black shale, which reach a thickness of 200 meters. As in Arkansas, it rests unconformably upon Silurian rocks and is conformable beneath the Mississippian. The Devonian is lacking in the central Texas district.

Rocky Mountains and Plateau Region. Devonian rocks are more widely distributed in this part of the United States than are the Silurian. In Nevada limestone 2000 meters thick and shale 700 meters thick have been referred to the Devonian; but G. H. Girty regards the upper part of the section as Mississippian. This section is said to be conformable with the beds both below and above. Northeastward, in northern Utah, these formations are represented by dark limestone, and in southwestern Montana by shale and limestone, having a total thickness of about 200—400 meters. There also, the Devonian is part of a continuous sequence from early to late Paleozoic. In Arizona and New Mexico the Devonian is represented by the Escabrosa limestone 30 to 100 meters thick; and in southwestern Colorado a limestone (the Ouray) which is partly of Mississippian age, rests upon a thin formation of sandstone and shale containing upper Devonian fossils.

Thruout most of Colorado, eastern Wyoming and South Dakota the Devonian formations seem to be lacking, and in many localities an unconformity between the Carboniferous and much older rocks has been recognized.

In California and Oregon Devonian beds have been identified at several widely separated places. The prevalent rocks are slates and sandstones with local beds of limestone. The only fossils which have been found in them are correlated with the upper Devonian faunas of the east, but it seems probable that the system is fully represented by a conformable succession of rocks from Silurian to Mississippian. Various estimates of thickness have been made in this region, the average being about 500 meters.

Mississippian (Lower Carboniferous).

General.

The Mississippian system is a little more widespread than the Devonian. It consists largely of limestone in the interior and western portions of United States, but clastic sediments predominate along the Appalachian Mountains. It has not yet been recognized in New England, altho portions of the beds in Maine, referred to the upper Devonian, may be of Mississippian age. It is known to be absent in some parts of the Rocky Mountains, where the Pennsylvanian strata rest unconformably upon older rocks. Almost everywhere it rests conformably upon the Devonian system where that is present. From Utah eastward the Mississippian and Pennsylvanian systems are generally separated by an unconformity which, however, is seldom markt by discordance of structures. In the western plateau region and in Montana, the two systems are said to be generally conformable.

The standard section of reference for the Mississippian system of the United States is in the central Mississippi valley, rather than New York. The Mississippi section is used for this purpose because it is fairly complete (only the uppermost beds being lacking) and because nearly all of the strata contain abundant marine fossils.

Local Occurrence.

Central Mississippi Valley. Along the Mississippi River, in Missouri and Illinois, the Mississippian rocks are well exposed and have been carefully studied. The period is represented by a succession of limestones which have an average thickness of 300 to 400 meters. Shaly and sandy phases are found at the bottom and near the top of the system. The section has been variously divided, but the generally accepted divisions are given in the accompanying table:

Mississippi River States.

4. Kaskaskia or Chester.
3. St. Louis.
2. Osage or Augusta (including Burlington, Keokuk and Warsaw).
1. Kinderhook or Chouteau.

The Kinderhook beds at the base are generally shaly, with intercalated limestones which expand in thickness southeastward in Kentucky and Tennessee. These beds are followed by the Osage series consisting of the Burlington, Keokuk, and Warsaw limestones. The St. Louis limestone lies above these and is rather sharply separated from them by an obscure unconformity and an abrupt change in the faunas. The Kaskaskia or Chester beds which terminate the section, consist of alternating sandstone and shale with some limestone, and the beds vary considerably from place to place.

The Burlington limestone of Iowa and Illinois has become famous for the wealth of crinoids which it contains. Many other formations in the system are equally rich in fossils of various kinds.

Ohio-Kentucky Region. On the east side of the Cincinnati arch the Mississippian strata consist largely of shale and sandstone (Waverly series). Between the Mississippi valley and this region various stages of gradation from the limestone phase to the shaly phase may be found. The chief limestones of the Ohio section are near the base and near the top of the system, contrasting in this respect with the Mississippi section.

Appalachian Mountains. From Ohio eastward to Pennsylvania the Mississippian system becomes much thicker and not only more clastic in composition but largely non-marine in origin. In the Pennsylvania section the Pocono sandstone grades down into the Catskill (Devonian) beds. This sandstone is devoid of marine fossils but contains thin shale beds with a few plant remains. It grades upward into the Mauch Chunk shale, a reddish or brownish alternation of shale and shaly sandstone. Ripple marks, sun-cracks, the footprints of amphibians and the root marks of plants are among the many indications cited by Barrell [1] as evidence that this formation is of continental origin.

The Mississippian rocks reach their maximum thickness (about 1500 meters) in central Pennsylvania. They become thinner southwestward along the Appalachian Mountains. In southwestern Pennsylvania a thin limestone (Greenbrier) separates the Pocono sandstone from the Mauch Chunk shale. This limestone increases in thickness to 70 meters in Maryland and 125 meters in parts of West Virginia. In the same districts the Pocono sandstone at the base becomes thinner, dwindling to 100 meters in

[1] Barrell, Joseph, Origin and Significance of the Mauch Chunk shale. Geol. Soc. of Am., Bull. XVIII, pp. 449—476, 1907.

Maryland and 30 meters in West Virginia, while the Mauch Chunk shale holds its thickness much better, being 250 meters thick in Maryland and 375 in West Virginia. Thru most of this region the Pennsylvanian rocks rest with an obscure unconformity upon the upper Mississippian strata; in northeastern Pennsylvania, however, there seems to be essential conformity between the two systems.

Farther southwest the limestone increases in prominence, while the clastic sediments below decrease. Thus in northeastern Tennessee the Newman limestone is 800 meters thick with a hundred meters or more of shale above and below, and in Alabama the system is represented by limestone and bedded chert 300 meters thick, with overlying shale and sandy beds (600 meters). As in the northern Appalachians, so in the south, the Mississippian system is usually limited above by an obscure unconformity beneath the Pennsylvanian. This probably accounts for the considerable differences in the observed thickness of the terrane in different localities. In Alabama even the base is unconformable on the Devonian according to recent studies by Butts.[1]

Southern Interior Region. West of the southern Appalachians, thru central Tennessee and Arkansas, the Mississippian system is relatively thin and consists largely of limestone. In central Tennessee shale and limestone, followed unconformably by a later Mississippian limestone, have an aggregate thickness of 160 meters. They appear to be limited both above and below by other inconspicuous unconformities. In northern Arkansas, the upper part of the Osage series is lacking. The rest of the system consists of limestone with some shale and sandstone, making an aggregate thickness of about 300 meters. There as usual the Pennsylvanian beds rest on the Mississippian unconformably. In southeastern Oklahoma the Boone chert, probably homotaxial with the Osage of Illinois, rests unconformably upon the upper Devonian shale. The middle Mississippian formations are represented by another similiar unconformity followed by shale and limestone correlated with the Kaskaskia of the standard Mississippi section. The whole system is there scarcely 150 meters thick. In the Ouachita mountains of Oklahoma an enormous thickness (3000 meters) of shale and sandstone has been referred to the Mississipian, but the facts are not yet clear.[2]

Michigan. In the shallow syncline which occupies much of the state of Michigan there is an isolated body of Mississippian strata. These resemble the Ohio beds more nearly than any others, but are exceptional in having layers of anhydrite and gypsum near the top.

Northern Rocky Mountains. The Mississippian limestones and shales of Missouri, Kansas and Nebraska disappear westward beneath the younger sediments of the Great Plains. Where the system re-appears in the Black Hills of South Dakota, it is represented by a massiv gray limestone 175 meters thick, which is separated by an obscure unconformity from Ordovician or Cambrian strata. From the description by Darton[3] it appears that the limestone grades upward into clastic beds of Pennsylvanian age.

A similar formation, the Madison limestone, encircles many of the isolated mountain groups of northern Wyoming and Montana. It is generally 200—300 meters thick and is succeeded, apparently conformably, by the Quadrant or Tensleep-Amsden sandstone and shale, with thin beds of limestone. A distinct unconformity has been

[1] Butts, C., and Burchard, E. F., Iron ores, fuels, and fluxes of the Birmingham district, Alabama. U. S. Geol. Survey, Bull. 400, 1910.

[2] Girty, G. H., The Fauna of the Caney Shale of Oklahoma. U. S. Geol. Survey, Bull. 377, 1909, p. 7.

[3] Darton, N. H., Geology and water resources of the northern Black Hills region, S. Dak. U. S. Geol. Survey, Prof. Paper 65, 1909.

found at this horizon in the mountains of western Wyoming but has not been reported elsewhere. The fossils in the Quadrant formation seem to be related to both Mississippian and Pennsylvanian faunas of the East, but especially to the latter. The Madison limestone has been traced into northwestern Montana and probably re-appears even in northeastern Washington.

Southern Rocky Mountains. When traced southward along the Rocky Mountains the Mississippian limestone becomes thinner or disappears entirely. In eastern Wyoming it is represented by the Guernsey limestone, in eastern Colorado by the Millsap limestone, and in central and southwestern Colorado by the Leadville and Ouray limestones respectivly. In nearly all of these localities the limestone is less than 100 meters thick and is separated from the overlying formations by an unconformity. Where the Devonian is present it lies conformably beneath the limestone. It is not improbable that the local absence of the Mississippian formations in the central Rockies is due to the removal of them by erosion just before the Pennsylvanian period.

In New Mexico and Arizona the Mississippian is again represented by limestone, usually lying conformably upon Devonian beds and often passing up without visible interruption into Pennsylvanian limestone. In the midst of this succession there is, however, rather generally a series of barren red sandstone and shale which is apparently of terrestrial origin.

Nevada. Mississippian formations have been detected at several points in Nevada but the correlation of them is still in doubt. At Eureka the Diamond Peak formation, which consists of quartzite with a little shale and limestone, is referred to the Mississippian by C. D. Walcott [1], and the White Pine shale formerly referred to the Devonian is now regarded by G. H. Girty [2] as Mississippian. The shale is 600 meters thick and rests conformably on Devonian limestone. The quartzite is nearly 1000 meters thick at Eureka, but seems to disappear rapidly southwestward, and has not been detected in other parts of the state.

California and Oregon. It is probable that Mississippian formations were deposited the entire length of the Pacific slope of North America, but owing to many later disturbances the rocks are now intensely folded and difficult to study. In northeastern California Mississippian sandstone and shale to a thickness of 1900 meters rest conformably upon Devonian beds. At the top of the section there are thin andesitic flows which obscure the relation of the Mississippian to the Pennsylvanian strata. At an adjacent locality the clastic beds alternate with beds of tuff and appear to be separated from the Devonian below by an unconformity.

Pennsylvanian (Upper Carboniferous).

General.

The „coal measures“ phase of the Pennsylvanian system, so long erroneously considered the typical phase, is found only in the eastern part of the United States. In the West the system is represented generally by limestone and shale, with some sandstone and red beds. Thruout that part of the country there is almost no coal, altho small deposits have been discovered in Arizona and New Mexico. Between the Rocky Mountains and the Mississippi valley a transitional phase is found in which the sediments are largely marine shales with limestone beds and a few seams of coal. Like the preceding system, the Pennsylvanian is rarely exposed east of the western

[1] Walcott, C. D., Paleontology of the Eureka district. U. S. Geol. Survey, Mon. VIII, 1884.

[2] (Emmons, W. H.), Reconnaissance of some mining camps in Nevada, U. S. Geol. Survey, Bull. 408, 1910, p. 20.

ranges of the Appalachian mountains. The chief exception to this rule is the small area in southeastern New England.

As stated above, the Pennsylvanian and Mississipian systems are generally separated from each other by a distinct unconformity. In some parts of central United States the beds beneath were gently folded and faulted before the deposition of the Pennsylvanian sediments. Between the Pennsylvanian and Permian system there is rarely any break. In the east and the west this is so true that there has been much dispute as to the exact horizon of the boundary line between the two systems. In the eastern interior of the United States the Pennsylvanian rocks are the youngest which are widely exposed. They therefore have broader outcrops than most of the earlier systems, and are found chiefly west of the mountains rather than in them. In the west the hard limestones and quartzites are prominent along the flanks of many of the mountain ranges and in the plateau region they lie at the surface over large areas.

Local Occurrence.

Appalachian Mountains. In Pennsylvania, the state from which the upper Carboniferous system has been named, the rocks of this age are divided into the Pottsville formation and the Coal Measures. The Pottsville is a coarse sandstone and conglomerate, which is about 500 meters thick in east central Pennsylvania but thins westward to 100 or 200 meters in the western part of the state and in West Virginia. Southwestward along the Appalachian Mountains a formation equivalent to the Pottsville, but often called the Lee conglomerate, lies unconformably upon the Mississippian shales and limestones. The Lee conglomerate reaches a thickness of 350 meters in Tennessee, and beds of the same age are considerably thicker (600 meters) in Alabama.

The Coal Measures consist of alternating beds of shale, sandstone and limestone with coal and iron ore. The series has been divided into three parts,—the Alleghany, Conemaugh and Monongahela formations. There are many beds of coal in the upper and lower divisions and some of them are thick, but the second contains few. The great Pittsburg seam has been traced horizontally over an area equal to that of an average state. The Coal Measures extend from northern Pennsylvania the entire length of the Appalachian Mountains, and in Alabama disappear beneath the Mesozoic beds of the coastal plain. In Pennsylvania their average thickness is about 300 meters, but they are much thinner in Tennessee and Alabama. In most of this region a large part of the Pennsylvanian system has been removed by erosion in the long interval since the beds were deposited.

New England and the Piedmont. The only rocks known to be of Pennsylvanian age in New England are those of the Narragansett and Worcester basins, in Rhode Island and Massachusetts. In the former locality, coal measures with a heavy basal conglomerate are estimated to have a thickness of 4000 meters. The sandstones and shales in the upper part contain a few seams of coal, which is so graphitic as to be of little value. All of the rocks are highly folded and somewhat metamorphosed. They are intruded by granite and other igneous rocks.

The finding of fossil plants apparently of Carboniferous age in the schistose complex of eastern Alabama suggests that the late Paleozoic rocks may be widespread thru the Piedmont province, altho now so metamorphosed as to be unrecognizable.

Michigan Basin. The Pennsylvanian rocks in central Michigan constitute an isolated basin, in which the succession bears little resemblance to that in other parts of the East. The rocks consist chiefly of sandstone with a little limestone, altogether aggregating about 160 meters in thickness. In the middle of the series a little work-

able coal is found. The system here rests unconformably upon the Mississippian, but without discordance.

Central Mississippi Valley. Pennsylvanian coal measures are widespread in the states of Indiana, Illinois, Iowa, Missouri, and adjacent regions. On the average they are thinner than in the East and consist much more largely of shale and limestone. At the base, and resting unconformably on the Mississippian, there is usually a sandstone, often called the Millstone grit, or designated by local names. This is but 40 meters thick in Indiana and in parts of Iowa and Illinois seems to be absent. The overlying coal measures consist largely of dark shale with interbedded layers of limestone and sandstone. There are several coal seams, particularly in the lower portion of the series, but they are fewer and on the average thinner than in Pennsylvania. The entire system has a thickness of 250 meters in Indiana and as much as 650 meters in Iowa and Missouri.

Arkansas and Oklahoma. In the mountains of Arkansas and Oklahoma and among the flat-lying beds north of them, Pennsylvanian rocks are widely distributed. In Arkansas, shales with interbedded sandstones and a few coal seams reach an enormous thickness (6000 meters according to Branner[1] and others). Farther west, in Oklahoma, similar masses of shale with sandstone and occasional beds of limestone (Caney formation) are 1000 to 3000 meters thick and contain fossils which have led G. H. Girty to regard the formation as early Pennsylvanian. In the Arbuckle mountains of Oklahoma a coarse conglomerate lies unconformably upon all of the Paleozoic formations and records an episode of folding and long erosion. The age of this formation is still in doubt but it is evidently either Pennsylvanian or Permian. Farther southwest an extension of these rocks is found in north-central Texas, where interbedded shale and limestone 1500 meters or more thick represent the system. In general the clastic beds seem to become thinner and the limestones thicker as they are traced westward.

Kansas and Nebraska. In these states the Pennsylvanian system shows a transitional phase from the coal measures of the east to the limestone of the west. The system is about 300 meters thick and consists largely of shale, with a little sandstone and considerable limestone. The coal beds are small and confined to the lower part of the formation. Here the system passes upward into Permian beds of similar thickness. There has been an attempt to draw a line between the two systems on the basis of contained fossils but as yet the matter is in dispute.

Rocky Mountains. The Rocky Mountains present several different phases of the Pennsylvanian system, but all are in contrast with those of the East, because of the lack of coal. In the Black Hills a buff and reddish sandy formation follows the Mississippian limestone, apparently conformably. Farther west in Montana the Quadrant and in Wyoming the Tensleep and Weber formations are somewhat similar. The basal parts of these terranes may prove to be Mississippian. Farther south the system consists largely of limestone,—more than 700 meters thick in southwestern Colorado. Usually there are reddish shales and sandstones at the base. In central Colorado a very different phase of the Pennsylvanian makes its appearance. Thus in the Denver basin 1300 meters of conglomerate, which is apparently of Pennsylvanian age, rests upon a thin limestone and black shale which contain Pennsylvanian fossils.

Basin Ranges and Plateaus. The prevailing rock in the Pennsylvanian system between the Rocky Mountains and the Sierra Nevada is limestone, generally dark gray or bluish in color, and often cherty. In northern Nevada there are two

[1] Branner, J. C., Thickness of the Paleozoic Sediments in Arkansas. Am. Jour. Sci., 4th ser., vol. 1, 1896, p. 235.

thick beds of limestone separated by the Weber conglomerate. The entire system there has a thickness of 3100 meters and is said to rest conformably upon the Mississippian quartzite below. In southern Nevada 800 meters of limestone, shale, and sandstone are referred to the Pennsylvanian system but seem to be separated from older rocks by an unconformity. In northeastern Utah the Pennsylvanian system comprises the Weber quartzite and underlying red shaly beds. This facies extends northward into Idaho and western Wyoming.

In the southern part of this district, thru Arizona and New Mexico to western Texas, the Pennsylvanian system is widely distributed and consists largely of limestone, with more or less shale. Locally there is red sandstone at the base. The system usually rests conformably on the Mississippian rocks beneath and apparently bears the same relation to the overlying Permian strata, where they are present. The system varies from a few hundred to more than a thousand meters in thickness.

Pacific Coast. Among the closely folded Paleozoic rocks of California and Oregon Carboniferous rocks have been detected in many localities. In some of these places it is not possible to correlate the rocks with even the larger divisions of the old Carboniferous system. In the northern Sierra Nevada, however, the Pennsylvanian is found to be represented by several distinct formations. The McCloud limestone, 700 meters thick, is followed by an alternation of conglomerate and beds of tuff, with thin lenses of limestone, altogether about 1000 meters thick. The fossils found are sufficient to establish the Pennsylvanian age of these beds but do not permit of refined correlations with divisions of the system elsewhere. In an adjacent locality in the same region, shale and quartzite with a little fossiliferous limestone are referred to the Carboniferous. The system has a thickness of about 2800 meters, but the upper and lower portions may be of Permian and Mississippian ages respectivly.

Permian.

General.

The Permian system is less widely distributed in the United States and not as well known as earlier Paleozoic systems. The marine beds of this age are confined almost entirely to the western mountains and the southwestern interior. In Texas the marine Permian is well developt and the Permian limestone extends northward thru the Great Plains as far as the Black Hills of South Dakota. The greater part of the Permian system in the western interior consists, however, of gypsiferous red beds. On the Pacific coast and in the western part of the Rocky Mountains there are other marine beds of Permian age. In the eastern half of the country the Permian beds are found about the head of the Ohio river. There they are simply a continuation of the Pennsylvanian coal measures, but they have been referred to the Permian on the testimony of the plant fossils which they contain.

Almost everywhere in the United States the Permian rocks are conformable on the Pennsylvanian below. The upper limit of the system is, however, generally markt by an obscure unconformity where overlying beds are present.

Local Occurrence.

Western Texas and New Mexico. The best section of the Permian rocks in the United States, and the one which may serve as the standard for this country, is probably that of the Guadalupe Mountains and adjacent ranges in the extreme western corner of Texas.

Unfortunately, there is still disagreement as to the exact correlation of the Texan and other sections in the United States and Europe. Girty[1] refers to the Permian

[1] Girty, G. H., The Guadalupian Fauna, U. S. Geol. Survey, Prof. Paper 58, 1908.

the Delaware Mt. formation (chiefly dark sandstone and shale) and the massiv white Capitan limestone. The entire succession is 700 to 800 meters thick. The limestones contain a wonderfully rich fauna which can be divided into several zones. According to RICHARDSON[1] the Capitan limestone is followed by Permian red beds, but the latter are separated from the Triassic by an unconformity.

Great Plains and Eastern Part of the Rocky Mountains. From central Texas to the Black Hills of South Dakota the Permian rocks are widely exposed both in the central part of the Great Plains and along the Rocky Mountain front. The prevailing rocks are the "Red Beds" which have often been called in the past Triassic or "Jura-Trias", but which are now known to be at least partly of Permian age. The Red Beds consist of an alternation of earthy red sandstone and sandy shale, containing beds of gypsum. Ripple marks and sun-cracks are prevalent. These rocks are generally devoid of fossils; but fragmentary fish remains and a few reptiles and amphibians have been found in them in the Rocky Mountains, while in northern Texas a varied but peculiar reptilian fauna is reported by S. W. WILLISTON. In northern Texas a three-fold division is given by CUMMINS[2],—the Wichita sandstone below, the Clearfork limestone in the middle, and the Double Mountain red beds with gypsum above. ADAMS[3] and others regard these formations as lithologic phases which are partly contemporaneous. The limestone becomes thinner northward but appears to be represented even in the Black Hills by a limestone (the Minnekahta) which is only 2—3 meters thick.

In Kansas, strata generally regarded as Permian (including Artinskian) comprise a thick succession of gray shale and limestone (the Big Blue series)[4], overlain by red beds and gypsum (Cimmarron series). The Big Blue series intergrades with the underlying Pennsylvanian. It should be added, however, that the propriety of referring these beds to the Permian is doubted by GIRTY.[5]

Westward in the Rocky Mountains of Colorado and southeast Wyoming the limestone disappears and the Pennsylvanian is separated from the late Jurassic by a series of red beds 300—600 meters thick which probably includes both Permian and Triassic systems, as well as part of the Jurassic. In southwestern Colorado and the Colorado plateaus, W. CROSS has ascertained that the Triassic portion of the Red Beds is separated by an unconformity and basal conglomerate from the Permian portion which in turn merges downward into Pennsylvanian limestone.

Utah to Montana. In the mountain ranges of northern Utah, southeastern Idaho, western Wyoming and southwestern Montana, the massiv Pennsylvanian sandstone is overlain by a succession of gray to black shales interbedded with limestone and chert, and containing important deposits of phosphorite. This series (Park City formation) is conformably overlain by gray shale and gray limestone characterized by a meager fauna, some of the fossils being Permian in aspect and others (*Meekoceras*) distinctly lower Triassic. In the Wind River mountains of Wyoming, strata (Embar formation) which are horizontally continuous with the Park City formation contain an abundance of fossils, some of which have Pennsylvanian and others Permian affinities.

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[1] RICHARDSON, G. B., Stratigraphy of the Upper Carboniferous in West Texas and Southeast New Mexico, Am. Jour. of Sci., vol. 29, 1910, pp. 330—332.

[2] CUMMINS, W. F., Report on the Geology of Northwestern Texas, Texas Geol. Survey, 4th Ann. Rep., 1893, pp. 179—238.

[3] ADAMS, G. I., Stratigraphic Relations of the Red Beds to the Carboniferous and Permian in Northern Texas, Geol. Soc. of Am., Bull. 14, 1903, pp. 191—201.

[4] PROSSER, C. S., Revised Classification of the upper Paleozoic Formations of Kansas. Jour. Geol., vol. 10, pp. 703—737, 1902.

[5] GIRTY, G. H., The Guadalupian Fauna. U. S. Geol. Survey, Prof. Paper 58, 1908.

Pacific Mountains. It is highly probable that Permian rocks are associated with the other Carboniferous formations of California and Oregon. In the Klamath mountains of southwestern Oregon, fossils thought to be of Permian age have been found in shale and thin beds of limestone with which basic lava flows are intercalated. In northeastern California there are also suggestions that the youngest formations beneath the Triassic limestone are of Permian age, but much additional study will be required to determine the facts in this region.

Upper Ohio Valley. In western Pennsylvania and adjacent parts of Ohio and West Virginia the uppermost part of the coal measures contains plants which are related to the Permian flora of Europe. The Dunkard formation, as these beds are called, consists of sandy shale with beds of freshwater limestone and a few thin coal-seams. Being the youngest formation in the region it has been largely removed and that part which remains is but 400 meters thick. Fossil plants and insects, which have been found adjacent to the coal seams, indicate that it represents only the earliest portion of the Permian period.

Triassic.

General.

Triassic rocks are found in three parts of the United States,—on the Pacific coast, in the Rocky Mountain region, and in the Piedmont-New England region of the Atlantic slope. In the first the beds are marine, but in the other two they are almost entirely of continental origin and suggest semi-arid or desert climates. The Triassic system is in some places unconformable upon the Permian, but in the Red Beds of the central Rocky Mountains and farther west there is apparent conformity. In the western states the Triassic formations represent all of the period, but on the Atlantic slope only the late Triassic beds are known.

Local Occurrence.

Pacific Coast. Triassic rocks are widely distributed in the states of California, Nevada, Oregon and Idaho, but they are still imperfectly known except in a few localities. Perhaps the best known section is that of the Redding region in the northern Sierra Nevada of California. The Pitt formation, consisting of tuff and other clastic sediments is several hundred meters thick. It is followed by the Hosselkuss limestone with a thickness of 85 meters, and that in turn by the Brock shale 130 meters thick. These are separated by an obscure unconformity from the overlying Jurassic beds. In the adjacent Taylorsville region the rocks are much thinner and the lowest appears to be absent, the Hosselkuss limestone resting unconformably upon Carboniferous rocks. In both of these localities only the upper Trias has been identified by fossils.

In Inyo County, California, rocks of lower and middle Triassic age lie conformably upon beds which are doubtfully referred to the Carboniferous. The Triassic here consists of limestone, overlain by calcareous shale.

Triassic rocks rise from beneath younger formations in southern and eastern Oregon and perhaps in other regions not yet investigated.

Rocky Mountains. The Triassic rocks of the Rocky Mountain region differ from those of the Pacific province in being of continental origin except in the northwestern ranges south and southwest of Yellowstone Park. Fossils are generally lacking, and because of the difficulty of determining the age of the beds the Triassic system is often grouped with the Jurassic under the name "Jura-Trias". It is equally difficult to separate it from the Permian system to which it bears a close lithologic resemblance.

In the southern Rocky Mountains and Colorado Plateau region Triassic red conglomerates and sandstones variously called the Dolores and Shinarump formations

have been shown to be separated from the Permian portion of the red beds by a persistent unconformity. In these beds a few fossil fishes and Unios have been found, along with characteristic Triassic reptils. In some places they appear to be separated from the overlying Jurassic beds by an unconformity, but elsewhere the relations are conformable or have not been determined. In northwestern Texas and in New Mexico the Dockum formation seems to be similar. It consists of cross-bedded white and red sandstones with conglomerate and mottled shales; the base rests upon the eroded surface of the Permian red beds. Triassic reptiles and Unios are the only fossils that have been found in it.

In the central and northern portion of the Rocky Mountains, namely, in Colorado, Wyoming and South Dakota, it is more difficult to separate the Permian from the Triassic. In southeastern Wyoming there is a series of red sandstone and shale with gypsum beds, which rests conformably upon the Pennsylvanian below but carries Triassic reptils near the top. These Permo-Triassic strata are 200—300 meters thick. Altho the Red Beds have thus been shown to be partly of Triassic age, it is now generally conceded that they are also partly Permian and probably in part Jurassic.

Along the western edge of the Rocky Mountain system from Great Salt Lake north by east to Yellowstone Park, the Triassic system is represented by an entirely different facies. There a conformable sequence of shale and limestone and sandstone extends from the Permian fossil-bearing beds up to the known Jurassic. The shales are generally deficient in fossils, but the limestone, which constitutes the middle portion of the sequence, contains abundant mollusks. Some of these are distinctly of Permian aspect, but the appearance of the ammonite *Meekoceras* seems to mark the limestone as early Triassic in age. The overlying red sandy shale and massiv sandstone should be in part Triassic and in part early Jurassic, since they pass upward conformably into the late Jurassic marine shale and limestone. Eastward in Wyoming these beds rapidly become thinner and the fossiliferous limestones disappear leaving the red shale and sandstone predominating.

Atlantic Slope. The great eastern interior of the United States is devoid of Triassic rocks, but isolated patches of them are scattered along the Atlantic coast from Nova Scotia southwest thru New England and Virginia to the edge of South Carolina. Generally they have been preserved during the general degradation of the region only where they are either folded down or faulted down into the older rocks. It is not known whether these scattered patches once formed a continous body, but it is probable that some of them where originally joined together.

In the Connecticut valley of Massachusetts and Connecticut the Triassic rocks consist of brown arkose and sandstone and dark shale with conglomerate at the base. Considering the small area which this formation covers, the thickness is great. Even after making due allowance for the many normal faults which have repeated individual beds, the estimates of thickness give 1000—3000 meters. In New Jersey and Virginia also the rocks (Newark series) are thick, and lithologically similar to those in New England. In southern Virginia the Newark rocks contain small coal seams. No early Triassic formations are known east of the Rocky Mountains. The plant remains in the Newark series are comparable to those of the Rhaetic of Europe, and the reptils likewise are of late Triassic types.

The sediments are interpreted by Fenner[1] and others as deposits made in broad river valleys under a semi-arid climate. Fossils are generally rare, the commonest being leaves of plants and skeletons of ganoid fishes. In a few localities the fishes

[1] Fenner. C. N., Features Indicativ of Physiographic Conditions Prevailing at the time of the Trap Extrusions in New Jersey. Jour. of Geol., vol. XVI, 1908, pp. 299—327.

have been found in large quantity. Bones of dinosaurs and great numbers of reptilian footprints are known from the Connecticut valley.

Contemporaneous volcanic rocks are intimately associated with the Newark series all along the Atlantic slope. Basalt flows are interbedded with the sediments, but pyroclastic beds are scarce. Large sills of diabase, such as that which makes the Palisades of the Hudson River, have been intruded into the strata in the same region, and it is thought that certain unaltered bodies of gabbro in North Carolina and in other parts of the Appalachian Mountains are of the same age.

Jurassic.

General.

With the exception of certain non-marine formations at the base of the Atlantic coastal plain, which have been referred by some to the late Jurassic and by others to the Comanchean (Lower Cretaceous), no rocks of Jurassic age are known east of the Rocky Mountains. A description of this system in the United States may therefore be confined to the western mountain region. In the Pacific ranges the entire Jurassic system seems to be represented by marine sediments, which contain fossils homotaxial with those of the familiar divisions of central Europe. Another small exposure of Jurassic rocks near the Rio Grande in western Texas has recently been made known by CRAGIN[1] and STANTON. The Jurassic rocks are exposed also in the northern part of the Rocky Mountains and in the eastern part of the plateau regions (Utah and Arizona). The rocks of this province are partly marine in the north but are terrestrial farther south.

Local Occurrence.

Pacific Mountains. In the northern part of the Sierra Nevada a thick series of Jurassic rocks has been studied in several localities. In Plumas County[2], California, the system is about 2500 meters thick and is separated from both Triassic and Comanchean strata by unconformities. There it consists of conglomerate, slate, and sandstone, with a little limestone. The beds appear to be largely of marine origin. At several horizons fossils have been found,—among them ammonites of the family *Arietidae*, and the mollusk *Aucella*. In most localities in California the Jurassic system contains beds of lava and volcanic tuff.

The Californian phase of the Jurassic has been traced northward into the Klamath mountains of Oregon and northeastward as far as the lower Snake River. In Oregon some of the sandstones contain Jurassic plants and are doubtless not marine.

Western Texas. The Jurassic rocks of Mexico extend northward along the Rio Grande into western Texas. In that locality the Malone formation consists of limestone and shale with several beds of calcareous conglomerate and a few of gypsum near the bottom. It seems to be more than 400 meters thick, but the rocks are so folded and faulted that neither its true thickness nor its relations to other formations are well known. Plentiful marine fossils in the Malone formation are related to the upper Jurassic faunas of Mexico and South America, but are distinct from those of California.

Rocky Mountains and Plateaus. Jurassic rocks are either absent or unrecognized over much of the southern part of the Rocky Mountains. From Colorado and Utah northward, however, the system is widely distributed. The fossiliferous strata

[1] CRAGIN, F. W., Paleontology of the Malone Jurassic Formation of Texas. U. S. Geol. Survey, Bull. 266, 1905.

[2] DILLER, J. S., Geology of the Taylorsville Region, California. U. S. Geol. Survey, Bull. 353, 1908.

are all of late Jurassic age, but it is probable that the barren red beds below represent earlier portions of the period. In Montana and South Dakota the upper Jurassic rocks are gray shales with beds and lenses of limestone and, locally, thick beds of sandstone. The sandstone is thickest in the upper portion and in the eastern part of the district. The shales and limestones contain many marine fossils, but the number of species is not great. The Rocky Mountain fauna is not related to that of the Malone formation of Texas or of California, but reflects rather the Alaskan facies. The marine Jurassic (Sundance or Ellis formation) in the northern part of the Rocky Mountains is generally less than 120 meters thick.

Southward in Wyoming and northern Colorado the Jurassic beds become thinner and less certainly marine. The limestones are replaced by shales and sandy beds, and it becomes difficult to discriminate the Jurassic from the overlying Comanchean strata. From east to west in Wyoming the marine Jurassic rocks increase rapidly in thickness. Northeast of Great Salt Lake a succession of gray calcareous shale and shaly limestone with the same late Jurassic marine fossils is 1300 meters thick. In the Uinta Mountains the drab oolitic and shaly limestones are 200 to 250 meters thick.

In southern Utah the Jurassic system if present is not marine. It is doubtless represented by barren white sandstones, such as the Kolob formation which is believed to be largely of eolian origin.

Atlantic and Gulf Coastal Plains. The basal formation of the coastal plain series in eastern United States has been referred by Marsh[1] and others to the Jurassic system. The testimony of the fossil plants and reptils is somewhat conflicting, but later studies by Berry[2] and others indicate that the Potomac series is related to the early Cretaceous of Europe.

Comanchean (Lower Cretaceous).

General.

The basal formations of the coastal plain, from near New York City to Alabama and again in Texas, are of lower Cretaceous age, or perhaps in part Jurassic. From Texas a sheet of Comanchean sediments extends north into Canada. Altho this underlies much of the Great Plains it is best exposed in the Rocky Mountains. Westward it extends as far as southern Arizona, but in general the Comanchean system is lacking in the western plateau region. The system re-appears on the Pacific slope, and in California attains great thickness. The Pacific phase is known to extend north and east into Oregon, as far as the Idaho boundary, but in California it does not pass east of the great valley.

In the eastern part of the United States the Comanchean system consists of clastic sediments and seems to be largely of terrestrial origin. In Texas marine strata predominate, but the marine beds do not extend far north of that state. In the northern part of the Great Plains and in the Rocky Mountains from Colorado to Canada, continental deposits again predominate. Thruout the eastern two-thirds of the United States the Comanchean system consists of unconsolidated or poorly indurated sediments. On the Pacific slope, however, the rocks are folded and solidified. They consist almost entirely of clastic sediments but are in part marine.

In the Rocky Mountains and Great Plains the Comanchean formations seem to lie conformably on the Jurassic system where that is present. In all other parts of

[1] Marsh, O. C., The Jurassic Formation of the Atlantic Coast. Am. J. Sci., 4th Series, vol. II, 1896, pp. 433—447.

Clark, W. B., and Bibbins, Arthur., The Geology of the Potomac Group in the Middle Atlantic slope. Geol. Soc. Am., Bull. XIII, 187—214, 1902.

[2] Berry, E. W., Lower Cretaceous, Maryland Geol. Surv., 1911.

the United States, however, the Comanchean rests with markt unconformity upon older rocks. On the Pacific coast there is no more conspicuous break in the entire stratigraphic column.

Local Occurrence.

New Jersey and Maryland. At the base of the coastal plain section in the central Atlantic states, lies the Potomac formation,—a complex series of sands and variegated clays, with irregular beds of gravel and thin local deposits of iron ore and lignite. The average thickness of the formation is about 200 meters. It lies almost horizontally upon deformed Triassic strata and ancient crystalline rocks, and from the upper Cretaceous rocks it is separated by an inconspicuous but persistent unconformity. Within the system there are minor local unconformities.

In the Potomac beds no certainly marine fossils have been found. The mollusks are represented by a few Unios; plants have been found in some abundance, and with them the bones of dinosaurs and turtles. The plants from the higher beds include great numbers of dicotyledons along with cycads and conifers. The plants therefore are distinctly Cretaceous in their relationships. The sauropod dinosaurs and other reptils led Marsh to join the Potomac series with the Jurassic system. The balance of evidence derived largely from the abundant flora seems at present to favor the view that the Potomac series is part of the Comanchean system.

Alabama-Mississippi Region. The Comanchean strata do not form a continuous belt along the inner edge of the coastal plain but are overlapt in the southeastern states and in the Mississippi valley by younger sediments. Where they appear in eastern Alabama they have been named the Tuscaloosa series. This formation, which exceeds 300 meters in thickness, is much like the Potomac formation previously described. Mottled clays and sands predominate and fossils are very rare. It is believed that the Tuscaloosa beds are of continental rather than marine origin.

Texas and Oklahoma. The Comanchean system is well known in Texas and its name comes from the tribe of Indians who once dwelt in that region. The system is there divided into three series. The basal or Trinity formation is sandy and its fossils are chiefly land plants. It is followed by the Fredericksburg formation, a thick layer of marl and chalk with abundant marine fossils. The uppermost, or Washita, series comprises alternate shale, sand and limestone, in which marine fossils occur only at infrequent horizons.

These beds are thickest in the southwest, along the Rio Grande and in southern Arizona, where they attain a depth of more than 1400 meters. In central Texas the system is about 500 meters thick and in southern Kansas, where only the Washita series is recognized, the thickness is but 70 meters.

The plants of the Trinity division consist largely of cycads and conifers, but the Washita formation has a flora in which dicotyledons predominate. The marine faunas are more closely related to those of southern Europe (Urgonian and Aptian) than to the faunas of approximately the same age on the Pacific coast.

Rocky Mountains. Formations now generally referred to the Comanchean system, but in earlier years often correlated with the Jurassic, are widely distributed from New Mexico north to the Canadian boundary. They are best known in the northern part of this region. Everywhere the rocks are of continental origin and so closely associated with the Jurassic beds on which they lie that it has been difficult locally to separate the two systems. In part of this region they also pass conformably upward into the (upper) Cretaceous rocks, and the two have not always been discriminated.

In Montana the Kootenay formation consists of variegated clays and sandstones in which a few coal seams have been found. Farther south in Colorado and

Wyoming partly equivalent formations are called the Morrison and Cloverly beds. The Morrison formation consists typically of variegated fresh-water clays in which the stumps and leaves of cycads have been found abundantly in a few places. In southeastern Wyoming, Colorado and elsewhere, skeletons of huge dinosaurs (*Sauropoda, Stegosauria, Ornithopoda,* etc.) have been unearthed. O. C. Marsh for this reason applied to the formation the name "Atlantosaurus beds". The Cloverly formation is more arenaceous in composition and frequently conglomeratic. It includes beside Comanchean beds some strata formerly referred to the Dakota sandstone of the Great Plains and thus of (upper) Cretaceous age. It is said to be separated from the Morrison beds by an unconformity in some places, but the break is thought to be of slight significance only.

The Comanchean system, as exposed along the east side of the Rocky Mountains is generally thin, averaging about 100 to 150 meters thick. On the western edge of Wyoming the system seems to comprise the upper part of the Beckwith formation,— a series of interbedded shale, sandstone and conglomerate which has a total thickness of 1200 meters. Thru most of the succession no fossils have been found, but a marine upper Jurassic fauna occurs near the base. The formation passes conformably into the overlying marine Cretaceous.

Arizona. Near Bisbee, in southeastern Arizona, the Comanchean period is represented by the Bisbee group, 1400 to 1600 meters thick. It consists of alternate shale and sandstone with beds of conglomerate. These beds do not contain marine fossils and the cross-bedded structure of the sandstones suggests continental deposits. In the midst of the series a layer of limestone 200 meters thick contains marine mollusks, corals and other fossils related to the fauna of the Fredericksburg series of Texas.

California and Oregon. In California, rocks of Comanchean age have long been known as the Shasta series. The rocks are best exposed along the Sacramento valley in northern California, but they have been identified also in southern California, in southwestern Oregon and even in extreme eastern Oregon along the Snake River. Where best known the Shasta series is enormously thick. Measurements as great as 8000 meters are reported, and a thickness of 4000 to 5000 meters seems to be not uncommon. The series is divided into the Knoxville beds below and the Horsetown above. The Knoxville formation consists largely of dark shale with many beds of sandstone. The Horsetown formation differs from it chiefly in being more sandy and containing many beds of conglomerate. The basal conglomerate of the Knoxville rests indifferently upon highly folded Jurassic or older sedimentary rocks and their associated intrusivs.

Like many other enormously thick formations, the Shasta series seems to be deficient in fossils. Land plants have been found at several horizons and marine fossils at others, but most of the beds are barren. It seems probable that a large part of the series is not of marine origin. The marine faunas, characterized by *Aucella*, show little relation to the Comanchean faunas of Texas, and among the land plants it is noteworthy that there are no dicotyledons, altho that group is well represented in the upper Potomac beds on the Atlantic Coast. The lower part of the Knoxville may be late Jurassic.

Cretaceous (Upper[1] Cretaceous).

General.

The Cretaceous system has much the same distribution in the United States as the Comanchean, but is on the average more extensivly exposed. It is much the most widely distributed system in the Great Plains of the western interior.

[1] In the following pages the word „Cretaceous" will be used to refer only to what is generally called the Upper Cretaceous, i. e., the equivalent of the Albian-to-Danian of Europe.

In the eastern part of the United States the rocks consist largely of clastic sediments with greensand. In the western interior they are shale with sandstone and chalk. On the Pacific coast the system is almost entirely clastic, and the coarser sediments are prominent. The greatest thickness of the Cretaceous system is found along the eastern side of the Rocky Mountains, where measurements exceeding 3000 meters have been made.

In the Atlantic and Gulf states the Cretaceous rocks are separated from the Comanchean system by an obscure but widely recognized unconformity. In the Great Plains region the two systems generally grade into each other without interruption. On the Pacific coast there is an unconformity between them in southern California and parts of Oregon, but in many other places in both states the succession seems to be conformable.

Local Occurrence.

Atlantic and Gulf Coastal Plain. Marine Cretaceous rocks are exposed in narrow belts east of the Comanchean outcrops in the coastal plain. In New Jersey and Maryland the rocks consist largely of dark clays with abundant greensand. With these are associated local beds of sand and a little limestone. The average thickness of the system is 100 to 200 meters, and the divisions are of local application only. The beds rest unconformably upon the Potomac series below and beneath the Eocene above. Marine fossils at many horizons make it possible to correlate these sediments roughly with the middle and late Cretaceous formations (Senonian-Danian) of Europe. The Cenomanian is thought to be represented by the basal plant-bearing clays (Raritan formation).

In Alabama and Mississippi the thickness of the Cretaceous system increases to more than 500 meters. At the base lignitic sands with greensand and phosphatic beds are overlain by chalky limestone and marl. The uppermost division consists of sands, sandy clays, and marl. Thruout this succession fossils are abundant. The basal sands contain leaves and wood of plants (Cenomanian?) but the higher strata yield marine fossils which indicate that these beds of the Gulf plain are somewhat older than those of New Jersey.

Great Plains and Rocky Mountains. A great sheet of Cretaceous rocks extends from Texas north into Canada and from near the Mississippi valley west to the edge of the high plateaus. The exposures are now interrupted here and there by the outcrops of both younger and older beds, but it is not improbable that the formations were once nearly continuous. In this broad area there are numerous variations in the character of the Cretaceous system, but nearly all of the local divisions may be referred to a general standard section for that region.

Perhaps the fullest section of the Cretaceous beds is to be found in the northwestern part of the Great Plains, in Montana, Wyoming and South Dakota. The thin basal sandstone, locally conglomeratic, is generally conformable upon the Comanchean beds below, or, if there is an unconformity, it is obviously slight. A great thickness of dark shales with beds of sandstone and lenses of limestone follows and is in turn overlain by a thin chalk formation. The upper part of the system consists of clastic beds which are shaly below and become progressivly more sandy toward the top. Coal seams are abundant and widely distributed in this upper portion.

Farther south in Nebraska and Texas, the sandy portion becomes less prominent and the limestone increases in thickness. Thus in Texas the chalk, calcareous marl and greensand are 300—700 meters thick, while the sandy coal-bearing beds are either thin or absent.

Westward in Utah and in New Mexico the limestone disappears and coal measures replace a considerable part of the marine shales of the standard section. For

example, in Utah there are two coal-bearing formations which are equivalent to the middle part of the Cretaceous of South Dakota. In New Mexico marine early Cretaceous (not Comanchean) shales are followed by coal measures.

The Cretaceous system of the plains region is usually fossiliferous. The oldest formation, which has been generally called the Dakota sandstone, is renowned for the wealth of dicotyledonous plant leaves which it has furnished. Other plants are found in association with the coal measures at various horizons in the system. The Benton, Niobrara, and Pierre formations generally contain marine fossils. These fossils show that nearly all of Cretaceous time is represented in that part of the United States. The Niobrara chalk has yielded many highly interesting vertebrate fossils, among which are the two birds, *Hesperornis* and *Ichthyornis*, and aquatic reptils such as *Tylosaurus*.

In Texas and in some other localities, the Cretaceous beds rest unconformably upon the Comanchean, but over most of the Great Plains it is difficult to draw a dividing line between them. From the overlying Eocene deposits they are generally separated by a markt unconformity involving structural discordance, but along the eastern side of the Rocky Mountains even this break is obscure. Hence there has been considerable dispute[1] as to what horizon marks the base of the Eocene in this region (see p. 41).

Pacific Coast. Cretaceous beds (Chico series) are widely distributed along the coast west of the Cascade-Sierra Nevada ranges in California, Oregon, and Washington. In Oregon they are known to extend east as far the Idaho boundary. The Chico consists of sandstone and shale with many thick beds of conglomerate. Altho horizontal in northeastern California, the formation has been folded in the Coast Ranges and is now found only in irregular patches. In some sections subsequent erosion has left only a slight thickness, while in others the strata are said to be more than 4000 meters thick. In the southern part of the Coast Ranges the Chico conglomerate rests upon the somewhat more highly folded beds of the Shasta series. In the Sacramento valley, however, the Shasta and Chico form one continuous series in which fossils afford the only means of distinguishing the rocks of the two periods. Like the Shasta series the Chico beds contain marine fossils at many horizons, but land plants at others. It is thought, from the characteristics of the system, that it is a coastal deposit which is partly of fluvial and partly of marine origin. The separation between Cretaceous and Eocene is much less distinct on the Pacific coast than in the Rocky Mountains.

Tertiary.

The Tertiary deposits of the United States are found chiefly in the West and around the shorelines. Only near the coasts are there marine strata. In the eastern interior region there are certain terrace deposits which may be Eocene, but their age is still in question. In the Rocky Mountains, the basin plateaus and adjacent portions of the interior plains, Eocene terrestrial formations are widely distributed but are found generally in isolated patches. These interior deposits have been well correlated by means of the abundant mammalian fossils which have been found in them.

Both in the coastal marine formations and in the terrestrial deposits of the mountains there are representativs of all divisions of the Tertiary system. Of these the Pliocene deposits are less well known and apparently less extensiv than any of the others. The divisions of the Tertiary system will be discussed separately in the following pages and given the rank of separate systems.

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[1] See recent papers by Knowlton, F. H., Stanton, T. W., Veatch, A. C., Cross, W. and others.

Eocene.

General.

Along the Atlantic and Gulf coastal plains the outcrop of the Eocene system is roughly parallel to that of the Cretaceous. It is less extensiv in the northeast, but somewhat more expanded in the Mississippi valley. On the Pacific coast both marine and non-marine formations of Eocene age are known. They are found in southern California, Oregon and Washington. In the basin plateaus, and particularly in the Rocky Mountains, Eocene deposits are widespread and often thick. They are wholly continental in origin.

Thruout most of the United States the Eocene beds are unconsolidated and nearly horizontal. In the central part of the Rocky Mountains they are gently folded in some localities, and along the Pacific coast they have been strongly folded and faulted. Locally in southern California Eocene strata are closely folded and have been metamorphosed by large igneous intrusions.

Thruout the Rocky Mountains and northern Coast Ranges the Eocene (exclusiv of Paleocene) rocks are generally separated from all older strata by a conspicuous unconformity. Elsewhere, however, the line of demarcation is either an eroded surface between parallel beds or is an indefinit horizon to be recognized only by faunal distinctions. Where the Oligocene overlies the Eocene the two are generally conformable.

Local Occurrence.

Atlantic Coastal Plain. A persistent but rather thin body of Eocene sediments extends from the vicinity of New York southward to the Carolinas. The average thickness is less than 100 meters and unconformities mark off the system from the adjacent formations above and below. The Eocene beds in this region consist largely of greensand and marl, with characteristic marine fossils.

Farther south upper Eocene limestone is exposed in the central part of the peninsula of Florida. It is the oldest rock in the state.

Gulf Coastal Plain. From Georgia westward to Mexico Eocene sediments are exposed in a nearly continous band. They consist generally of alternating beds of clay and sand, with occasional layers of limestone and coal. Some of the formations contain marine fossils, while others yield only land plants. It has been found that even the marine beds tend to pass into the lignitic phase when traced landward. The system is about 400 meters thick in Georgia, but the thickness gradually increases to about 1200 meters in eastern Texas. It probably represents all of the Eocene period, since it appears to be locally conformable with both Cretaceous and Oligocene formations. A slight unconformity has been detected at the base in several parts of the southern coastal plain, but in general it has not been recognized and there may be a transition from Cretaceous to Tertiary. It is said that no Cretaceous species passes up into the Eocene. Perhaps the paucity of good exposures explains the failure to detect a general altho obscure unconformity.

Pacific Coast. From southern California to Puget Sound in Washington, marine and continental Eocene strata have been found at scattered intervals. They are thickest in the north, and the marine portion of the system is generally found only near the present coast line.

In the Coast Ranges and interior valley of southern and central California there are two Eocene formations,—the Martinez below and the Tejon above. The Martinez formation consists of sandstone and shale with greensand, 300 to 600 meters in thickness. It is conformably overlain by the Tejon, the separation of the two formations being made on the basis of faunas. The Tejon formation consists of sandy shale and sandstone,—the shales predominating in the upper portion. The Eocene

formations are generally conformable upon the Chico (Cretaceous) but in Oregon and Washington the Eocene rests on eroded Comanchean or older strata. The average thickness seems to be 700 to 1000 meters. In northern California Eocene rocks are not widely known and are generally thin.

In western Oregon the Eocene is represented by a great thickness of sandstone, shale and conglomerate, within which there are local beds of volcanic tuff and coal. Near the present coast line marine fossils are commonly found in these beds, but farther inland land plants predominate. The maximum thickness of these strata is estimated to be more than 3000 meters. Erosion has removed most of the beds except in the deeper synclines.

Near Seattle, in northwestern Washington, similar Eocene sediments are called the Puget series. This has an estimated thickness of more than 3000 meters, and consists of impure clay and dark arkosic sand with but little conglomerate and no limestone. In the lower portion 125 workable seams of coal have been found. With these and many thinner coal beds are associated abundant remains of plants, which include such semi-tropical species as palms, figs, magnolias and ferns. No marine shells have been found in the entire series. This formation, together with the beds in Oregon, have been interpreted as coastal plain deposits made in a moist climate and with highlands adjacent on the east.

Eastern Rocky Mountains. Where the Rocky Mountains and the interior plains intergrade, terrestrial Eocene deposits are well developt in some places but absent in others. Some of the formations are so intimately related to the Cretaceous that their exact age is a matter of controversy.

In central Montana the Fort Union formation reaches a thickness of 2800 meters. It consists of rapidly alternating beds of dark sandstone and shale, with local beds of volcanic breccia and tuff. The coarser strata are cross-bedded and laterally inconstant. It contains a few fresh water mollusks *(Unio)*, rare Paleocene mammals *(Ptilodus)*, and the leaves of plants which show relationships to both Cretaceous and Eocene floras. The series rests in apparent conformity upon the Cretaceous and is upturned with it, except locally (western Wyoming), where it is less folded than the Cretaceous system.

In southeastern Colorado the Cucharas and related formations consist of a thick succession of conglomerates, sands, and shales, which contain no fossils. They are somewhat closely related to the Cretaceous system but are believed to record, in their composition and structure, the making of the Rocky Mountain folds, an event which marks approximately the close of the Cretaceous period.

In the vicinity of Denver (Colorado), the well known Cretaceous beds are overlain by two unconformable series of deposits which are referred by some[1] to the Cretaceous and by others[2] to the base of the Eocene. They are perhaps best regarded as transitional. The lower or Arapahoe formation consists largely of volcanic breccia, while the upper or Denver beds are conglomerate and sandstone. The dinosaur bones that have been found in these strata give them a likeness to the Cretaceous system, but the evidences of general disturbance and volcanic activity are more consistent with early Eocene history.

Western Rocky Mountains. The best known Eocene deposits of the western interior occupy a series of isolated basins extending from northern Wyoming southwest through Utah and Colorado to New Mexico. Altho the rocks in these basins are variable, and individual strata cannot be correlated from place to place, the deposits have

[1] Stanton, T. W., Succession and Distribution of later Mesozoic Invertebrate Faunas in North America. Jour. of Geol. Vol. 17, 1909, pp. 410—423.

[2] Chamberlin, T. C., and Salisbury, R. D. Geology, Vol. 3, 1906.

the same general characteristics. They consist of variegated shales with sandstone beds and occasional lenses of fresh water limestone. Conglomerate is often an important constituent of the system, and locally great masses of volcanic breccia and tuff are included. In the limestone beds, fishes and fresh water mollusks have been found in considerable abundance, while the leaves of palms, magnolias and other semi-tropical plants are widely distributed. The most important fossil remains are those of mammals. By means of the abundant skeletons which have been collected from various localities is has been possible to work out a full succession of Eocene faunas from the primitiv Mesozoic assemblage of the Puerco, which appears to be transitional from Cretaceous to Tertiary, to the highly developt forms of the Uinta, the age of which is late Eocene. There is perhaps no other district in the world in which Eocene vertebrates are more abundant or have been more thoroly studied.[1]

Western Basin and Plateau Region. Between the numerous mountain ranges of this district there are widespread unconsolidated deposits of Tertiary and later age. Locally beds of Eocene age been identified, and it is probable that they exist in many other localities where fossils have not been found. Volcanic flows are widespread from Oregon to Wyoming.

In the northern part of this region, east of the Cascade Mountains of Washington, the Swauk formation consists of coarse sandstone, conglomerate and shale, with a total thickness of 1800 meters. In some places this series contains coal seams and the leaves of plants allied to those of the Puget formation farther west. The sediments are interbedded at various horizons with rhyolitic and basaltic flows. These predominate in the upper portion, sometimes to the exclusion of the sediments. In one district the flows are 2000 meters thick.

Oligocene.

General.

The Oligocene system of the United States is so closely linkt with the Eocene that the two generally form a stratigraphic unit. In most places the Oligocene formations can be distinguisht only by means of paleontological evidence, and in some places this separation has not been clearly made. The Oligocene is usually conformable upon the Eocene where the latter is present, but is generally more sharply set off from younger formations. It is much more widespread than the Eocene in the Great Plains but the reverse is true in the Atlantic coast and Rocky Mountains.

Local Occurrence.

Atlantic and Gulf Coastal Plain. Marine Oligocene formations extend from Texas thru the southern coastal plain as far as the Carolinas. Small patches have been identified farther northeast. Perhaps the best known section is that of the lower Mississippi valley, in the states of Louisiana and Mississippi. There the Vicksburg limestone, of lower Oligocene age, rests conformably upon the uppermost Eocene. It is 20—60 meters thick and consists of alternate limestones and beds of marl that contain marine fossils. Upon the Vicksburg limestone rest sandstone and clay with the leaves of land plants. That in turn is followed by red clay containing only brackish water shells. The two formations attain a thickness of more than 400 meters. Thruout this region the Oligocene formations are separated from the later Tertiary beds by an unconformity, which is obscure only because the beds both above and below are undisturbed.

According to Sellards[2], the Oligocene is represented by two formations, the

[1] See summary by Osborn, H. F., Cenozoic mammal horizons of western North America. U. S. Geol. Survey, Bull. 361, 1909.

[2] Sellards, E. H. Florida State Geol. Survey, 2nd Ann. Rep., 1909.

Vicksburg below and the Appalachicola above, separated by an obscure unconformity. The older formation is chiefly limestone with beds of marl and chert, while the younger terrane contains a larger proportion of clay and sand. The total thickness of these beds reaches 200 meters.

Only scattered patches of the Oligocene beds have been found along the Atlantic slope. They are exposed chiefly in South Carolina and New Jersey. It is thought that much of the Oligocene was removed during a later period of erosion, and that the edge of the series has been generally overlapt by Miocene or later beds.

Great Plains. One of the most widespread Tertiary formations in the Great Plains, from South Dakota and Montana south to Colorado, is the White River series. The Chadron sand at the base is usually but 50 to 60 meters thick; it grades upward into a much thicker formation (Brule) of soft clay with thin beds of sandstone and even fresh water limestone. Scattered thru the clay are numerous concretions of iron-stone. In detail the White River beds vary from place to place and, altho the formation was formerly interpreted as a lake deposit, it is now generally conceded that it was laid down partly by rivers, partly by the wind, and only subordinately in lakes. The great numbers of fossil mammals which have been exhumed from it represent the ancestors of the present fauna of the Great Plains. According to Osborn[1] they indicate a lack of free communication with Europe, in contrast with the conditions in the early Eocene.

Rocky Mountains and Western Plateaus. Scattered thru the western mountain region there are terrestrial deposits, much like those of the Eocene, which contain fossil mammals of Oligocene age. One of the best known localities is in the John Day River basin of north central Oregon. There a thick deposit, consisting largely of fine volcanic ash, covers some thousands of square miles. At various horizons thruout the formation the bones of mammals and the stumps and leaves of trees have been found. These seem to indicate that the John Day beds are of rather late Oligocene age and perhaps partly Miocene.

At Florissant in central Colorado a similar but much smaller Oligocene deposit consists largely of fine volcanic tuff in which were intombed myriads of insects and many plant leaves.

Pacific Coast. Along the Pacific coast of the United States Oligocene beds are less widespread than the Eocene deposits. The deposition of the Puget series in northwestern Washington is thought to have continued thru the Oligocene period. Along the coast of Oregon, the Aturia and lower Astoria beds contain marine Oligocene fossils. In California the Miocene beds usually rest unconformably upon Eocene or older formations. In the Santa Cruz district in the central part of the Coast Range, however, 1500 meters of sandstone and clay shale have recently been referred to the Oligocene on the basis of marine fossils. These beds are distinctly unconformable beneath the Miocene but their relation to the Eocene strata is still unknown.

Miocene.

General. The distribution of the Miocene in the United States is similar in general to that of the early Tertiary formations, and lithologically the two are much alike. Miocene strata are better developt on the Atlantic coast than the Oligocene but not so well on the Gulf coast. They are exposed farther northeast than any other Tertiary formation, having been traced as far as southeastern New England. Along the Pacific coast the Miocene deposits are much like those of the early Tertiary. In the Rocky Mountains and the Great Plains the same is true, altho in many places the

[1] Osborn, H. F., Cenozoic Mammal Horizons of western North America. U. S. Geol. Survey, Bull. 361, 1909.

sediments are coarser than the Eocene deposits. In the northern Rocky Mountains and the Columbia Plateau region, as well as in the Pacific mountains there are great accumulations of volcanic breccia, tuff, and flows, which are largely of Miocene age. Probably there is no other system in the United States, unless it be the Pre-Cambrian, that includes greater quantities of such volcanic materials.

The Miocene system is generally separated from the Eocene and Oligocene by an unconformity. In the Coastal Plain region all the beds are horizontal, and the unconformity is therefore obscure. On the Pacific coast, however, and in some parts of the western interior region the lower Miocene beds are conformable on the Oligocene, where that is present.

Local occurrence.

Atlantic and Gulf Coastal Plain. Miocene beds are exposed on the island of Martha's Vineyard on the southeastern coast of New England and thence with some interruptions southwestward to Florida and westward parallel to the Gulf coast into Texas. That the formations were once more extensiv than now, is indicated by the outlying patches of Miocene deposits, which lie some distance inland from the present outcrop.

In the middle Atlantic states the Miocene period is represented by the Chesapeake (or Yorktown) formation, which consists of sands and variegated clays with local beds of infusorial earth near the base. It contains a varied marine fauna which has been thought to indicate a climate somewhat colder than that of the preceding period. The Chesapeake overlaps not only the Oligocene but in places the Eocene and Cretaceous deposits as well.

Miocene beds 10—150 meters thick, underlie most of the peninsula of Florida. Limestone prevails on the east, but on the west shell-marl replaces it. The Florida Miocene seems to rest on the eroded surface of the Oligocene.

In the Gulf states the Miocene system is generally concealed beneath younger beds. Along the Mississippi embayment it is represented by the unconformity between the Pliocene and Oligocene. In Texas there are terrestrial beds thought to be of Miocene age, and several deep borings have shown that near the shore of the Gulf of Mexico marine Miocene strata are concealed by the overlying deposits. Such a well at Galveston penetrates more than 1500 meters of sand and clay containing marine fossils largely of Miocene age. It appears that a considerable part of the oil of southeastern Texas is derived from concealed Miocene beds of similar character.

Great Plains. Along the eastern slope of the Rocky Mountains and in the Great Plains, from the Dakotas south to Texas, Miocene strata are widely distributed. They are all terrestrial deposits and in general resemble those of Eocene and Oligocene age in the same region.

In Nebraska and Wyoming the Miocene beds consist of soft sandstone and clay, with local beds of conglomerate. The average thickness is 300 meters or less, and the formation probably represents most of the Miocene period. In the past, part of these sediments have been called the Loup Fork stage, but the name is not now in good use because of misunderstandings as to its scope. From the Arikaree beds an interesting series of early Miocene fossils has been exhumed,—chiefly mammals closely related to the preceding Oligocene forms. The middle and upper Miocene beds contain a very different assemblage of mammals among which there are types which had immigrated from Europe and Africa.

Western Mountains and Plateaus. Miocene formations are distributed somewhat widely over all of the Cordilleran states. They have been little recognized in Arizona and New Mexico, but are more important in the northern states. In the Columbia Plateau of Oregon, Washington and Idaho, the Miocene system consists of a

thick succession of basalt flows with which layers of river sand and gravel are locally interbedded. The flows cover an area of about 500,000 square kilometers and in many places are more than 1500 meters thick. Altho they are still nearly horizontal they have been gently folded along the western edge of the plateau. In central Washington and Oregon, and doubtless in other places as yet unknown, the flows are overlain by beds of gravel and sandstone, which appear to have been deposited by streams flowing from the mountains on the west. One of these terranes (Ellensburg) in Washington, has yielded Miocene plants, and the Mascal beds of Oregon a considerable number of mammals which seem to belong to late Miocene times.

In western Montana an intermontane basin contains fluvial deposits,—gravel, sand and loam mingled with quantities of volcanic ash and breccia (Bozeman beds).[1] In Yellowstone Park in northwestern Wyoming, great thicknesses of volcanic breccia testify to the frequent eruptions from Miocene volcanoes in that region. Petrified stumps of trees have been found imbedded in these volcanic deposits.

Pacific Coast. Marine Miocene beds appear at intervals along the coast ranges of California, Oregon and western Washington. Near the mouth of the Columbia river the Astoria sandstone contains a characteristic Lower Miocene fauna. Somewhat farther south in Oregon Upper Miocene fossils have been found in the Empire formation, which rests unconformably upon folded Eocene-Oligocene rocks. In southern California the Monterey shale, with the Vaqueros sandstone, represents the earlier part of Miocene time. The San Pablo formation seems to be late Miocene or perhaps partly Pliocene. Both of these formations are marine and contain fossils. Part of the Monterey formation consists of volcanic tuff, together with diatomaceous chert and slate which contain petroleum. The entire sequence of these beds is estimated to be more than 2500 meters thick.

In northern California, particularly in the broad Sacramento valley, the marine Miocene is supplanted by fresh water beds (Ione formation), consisting of sand, gravel and clay, with thin beds of coal and iron ore. Except plant leaves and Unios, fossils are rare. Near Redding, California, the Ione formation is 350 meters thick, but elsewhere it may be thicker. Still farther east in the Sierra Nevada mountains, the older auriferous gravels are now found in flat-topt divides between the canyons. During Miocene time they were deposited in open valleys, but before the close of the period they were generally buried by lava flows and beds of hard volcanic breccia, which now form the caps of these divides.

Pliocene.

General. Deposits of Pliocene age have been found in but few parts of the United States. The best known occurrences are those in California, northern Texas and western Nebraska. On the Pacific coast there are thick deposits which are partly of continental and partly of marine origin.

In general there is much less volcanic material in the Pliocene formations than in the earlier Tertiary deposits. Locally, however, as in Yellowstone Park, the amount is large. The Pliocene deposits are generally unconsolidated and even where the Miocene beds are folded, as on the Pacific coast, the Pliocene formations are but little deformed. The system is generally unconformable upon the rocks below.

Local occurrence.

The Eastern Coastal Plain. The Pliocene formations of the coastal plain have been the subject of much dispute, partly because of the inconstancy of the strata and partly because of the general lack of fossils. Pliocene formations with marine

[1] Three Forks, Mont. folio (No. 24). Geol. Atlas of U. S., U. S. Geol. Survey, 1896.

fossils are found at a few scattered points from southeastern Massachusetts thru Virginia and Georgia to Florida. They rest unconformably upon Miocene sediments and are overlapt by the Pleistocene beds. In Florida the Pliocene is represented by clay and shell marl only 2 to 4 meters thick. West of Florida in the Gulf coastal plain, marine Pliocene beds have not been found exposed, but strata thought to be of that age have been pierced by borings near the present coast.

An extensiv and complex formation known as the Lafayette, is generally regarded as Pliocene, altho by some it has been correlated with the early Quaternary. The Lafayette formation consists largely of buff to orange sand with beds of gravel, silt and clay. The beds are lenticular in form and irregularly stratified. The materials have been found to consist of the insoluble residue of many kinds of rock, so that there is but little in it which can be further dissolved or oxidized. Fossils are generally rare. Those which have been found represent land animals and plants. The prevailing interpretation of the Lafayette formation is that it is of fluviatil origin,—a broad coastal plain deposit. The Lafayette sediments extend farther inland than almost any of the other coastal formations. Along the inland border of their outcrop they usually occupy the tops of hills, the intervening portions having been removed during the erosion of the valleys. Farther south and east they sink to the level of the present valleys and constitute a more continuous sheet covering the older formations. They are thin in the north and northwest, but thicken when traced toward the Gulf and the Atlantic ocean.

Great Plains. In northwestern Texas the Blanco beds of the Staked Plains have yielded large numbers of early Pliocene mammals. Among them are several members of the South American Tertiary fauna, such as *Mylodon*, *Megalonyx*, and armadillos. The sediments are much like those of Miocene and Eocene age thruout the Great Plains. Similar beds are found in western Nebraska and Kansas, where they are associated closely with Miocene sediments. While the lower part of this (Ogallala) formation seems to be late Miocene, the upper part contains fossil mammals indicativ of early Pliocene age. In central Nebraska, later Pliocene beds are known as the *Elephas imperator* zone.

Western Mountains and Plateaus. In the interior of the Cordilleran mountain region Pliocene beds have not been recognized with certainty. It is hardly to be doubted, however, that they exist among the many Tertiary deposits between the mountain ranges. Gravels resting on high terraces and mesas may not improbably belong in part to the Pliocene, but a means of determining their age has not yet been found.

Pacific Coast. The coast ranges of California, Oregon and Washington consist chiefly of Tertiary strata. The folded beds are largely Miocene or older, but along their flanks are found moderately inclined or horizontal strata of Pliocene and Pleistocene age.

In southern California a succession of sandy clays, sands, and conglomerates, 300—600 meters thick, ranges from late Miocene to early Quaternary. It has a thick basal conglomerate, resting unconformably upon folded early Miocene strata. Farther north near San Francisco, similar rocks are variously estimated to be from 100 to 1500 meters thick. These beds appear to be largely of terrestrial origin except near the present coast, where they generally contain marine fossils.

In Oregon and Washington Pliocene beds have not been positivly identified, altho it is probable that this period is represented among the more recent coastal formations.

Quaternary.

General.

The most distinctiv and best known Quaternary deposits in the United States are the glacial formations. These cover most of the northern states from Montana to Missouri and east to New Jersey and New England. Much smaller and generally isolated patches of glacial material are scattered thruout the western mountain region, especially in the northern states.

In addition to the glacial drift there are widespread Quaternary formations which are in general like those of the Tertiary system. They consist of river sediments, lake sediments, wind-blown sand, and occasional volcanic deposits. The volcanic rocks are confined to the western part of the country, but the rest are scattered over the southern and middle states generally. The marine formations are found only close to the present coasts.

Marine Deposits.

Marine sediments are found only here and there along the edge of the United States and extending back up some of the larger valleys. Landward they generally pass into river-made deposits which are equivalent to them in age.

Florida. Pleistocene limestone, variably oolitic, marly or shelly, like the deposits now in process of formation along the coasts of the peninsula, are found a little above sea-level near the present shore. Younger formations include much sand on the east coast. In several scattered borings the Pleistocene limestone has been found to be 20—40 meters thick and the upper sandy beds 10—30 meters thick.

Atlantic Coast and Embayments. Marine Quaternary deposits are found in but few places along the Atlantic coast and cover only small areas. Sandy beds with marine shells occur along the coast of New Jersey a few meters above the present sea level. At the head of Delaware Bay, near the city of Philadelphia, a thin deposit of clay with marine diatoms is now 20 meters above sea level. On the coast of Maine, marine clays with shell banks lie 75 meters above the present sea level, upon a rugged coast.

The most extensiv deposit of marine Quaternary beds in this part of the United States, is found in the valley of the St. Lawrence river and along the shores of Lakes Ontario and Champlain. There stratified clays with occasional layers of sand and gravel contain boreal marine shells, such as *Leda, Astarte* and *Mya,* as well as the bones of the whale and walrus. The beaches with which these clays are associated are now 100 meters above sea level in the Hudson river valley, somewhat more along Lake Champlain and the St. Lawrence river, and fully 200 meters high at the western end of Lake Ontario. These deposits are of late Quaternary age, for they lie upon the drift deposited by the latest ice sheet.

Pacific Coast. Marine Quaternary formations, much like the preceding Tertiary systems, are found here and there along the Pacific coast, but in each instance very close to the present shore line.

In southern California, the San Pedro formation represents the Quaternary. This is divided into two members, the lower being gently folded and separated from the horizontal upper beds by a markt unconformity. Both formations consist of sand and gravel, which contain marine fossils indicativ of a climate somewhat colder than the present.

Thin deposits of marine sand and clay have been found on ocean terraces along the coast of Oregon, at various elevations up to more than 300 meters above sea level. It is probable that there are similar deposits on the coast of Washington, but as yet they are but little known. Much of the western part of that state was covered by

glaciers and thus the deposition of marine sediments during the Quaternary period was partly prevented.

Glacial Formations.

Glacial deposits predominate in the northern and northeastern part of the United States, as well as in smaller areas in the West.

The great ice sheets which descended from Canada left a series of deposits over northern United States. Among them are many kinds of materials in complex surface relations. The general distribution of drift sheets is indicated on the map below.

In general, the deposits of glacial drift may be classified as till (unstratified drift) and stratified drift. The former has been deposited directly by the ice, while the latter has been effectivly workt over by water, usually derived from the melting of the ice. In the glacial deposits these two kinds of material are generally separated into distinguishable

Fig. 3. Map showing the outer edges of the three principal drift sheets in eastern United States and the larger areas of local glaciation in the western mountains. (Modified after F. Leverett, 1910.)

bodies, but in many places they are confusedly mingled. Terminal moraines were probably formed along the edge of each of the ice sheets, but only those of more recent age are now well preserved. The moraines are groupt in a series of festoon-like curves, corresponding to the lobate edge of the ice-sheet itself, the recessional moraines making concentric loops within the outer ones.[1] The moraines generally consist of till associated with much stratified gravel and sand. Gently undulating plains of till lie behind the moraines, while outside of them the stratified drift forms plains or terraces along valleys. Where there were lakes which had been filled by sediments washed into them, plains of stratified lacustrin clay are now found. These are particularly characteristic of the abandoned shores which surround the Great Lakes, but they also mark the sites of many small ponds and lakelets scattered over the glacial deposits. In the more mountainous regions of eastern United States, where well defined moraines are less common, the original valleys are more or less obstructed with quantities of glacial till, which have no distinctiv forms of their own.

[1] See Fig. 22.

In the central interior region, particularly in the vicinity of the Mississippi River, many of the glacial deposits are overlain by loess. This is now found chiefly upon the hilltops and in the cliffs bordering the streams. It is a fine unstratified loam or clay, with the usual characteristics of loess. Fossils are rare, but some land mollusks and bones of mammals have been found. The loess has an average thickness of not more than 10 meters, but is distributed over a wide area from Nebraska to Indiana and from Wisconsin to the Gulf of Mexico.

A careful study of the glacial series has shown clearly that it consists of several sheets of drift of different ages. The oldest drift sheet now exposed has been deeply eroded and has entirely lost its distinctiv glacial topography. The younger sheets have suffered less change, and the youngest seems as fresh as when it was deposited. The making of each successiv sheet of till doubtless involved the destruction of most of the preceding sheets, so that it is chiefly around the edges of the younger drift deposits that the older can now be found. Not all of them occur in any one locality, and it is therefore not yet possible to correlate definitly the older drift deposits in one region with those of another. Between the sheets of till stratified deposits have been found in many localities. In the Aftonian gravels of Iowa and in some of the later deposits Calvin and Shimek found plant remains and the bones of Quaternary mammals[1], which indicate a comparativly mild climate. These are regarded as inter-glacial deposits. The full succession of glacial and inter-glacial formations, as determined by Chamberlin and others, is given on p. 117. There is a disposition in recent years to countenance a reduction in the number of distinct drift sheets on the ground that some of the inter-glacial deposits may represent merely temporary retreats of the ice-sheets, rather than a total disappearance of them. Thus Leverett[2] would omit the Iowan drift as a distinct member of the series.

Western Mountain Region. In the West the Quaternary glacial deposits may be divided into the local deposits of alpine glaciers and the much more extensiv moraines left by great piedmont lobes from Canada.

Small valley glaciers are still to be found among the highest peaks of both the Rocky Mountains and Pacific ranges. In the glacial period these were much larger and there were many others in somewhat lower ranges. In general, the glaciers were most abundant in the northern part of both mountain systems and particularly in the Sierra Nevada and Cascade ranges. The southernmost glaciers, which occupied lofty peaks in northern Arizona, New Mexico and southern California, were very small. The heavier snow-fall along the Pacific coast was doubtless the cause of the abundance and great size of the glaciers in that part of the West. In the Rocky Mountains an elevation of nearly 3000 meters was required to produce glaciers in Montana and Idaho. Farther south this elevation rises gradually until in northern New Mexico only peaks which were more than 4000 meters high were inhabited by glaciers. The deposits of these alpine glaciers consist of prominent lateral and terminal moraines. Below the terminal moraines trains of outwash gravel extend down the valleys and now stand as terraces above the present streams. Within the moraines the sites of former lakes are commonly occupied by flat meadows or open plains, the underlying material of which is stratified sand and clay. The glacial deposits of the western mountains belong to two and probably three distinct time divisions separated by long interglacial epochs.

Along the northern boundary of the western states, from western Montana to the Pacific Ocean, broad glacial lobes descended from the great ice fields of British

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[1] Calvin, Samuel, Present Phase of the Pleistocene Problem in Iowa. Geol. Soc. of Am., Bull. XX, 1909, pp. 133—152.

[2] Leverett, Frank, Comparison of North American and European Glacial Deposits. Zeitschrift für Gletscherkunde, vol. 4, 1910, p. 282.

Columbia and choked all of the principal valleys leading into the United States. Several of these lobes were 30 to 50 kilometers in width and the Okanagan lobe of central Washington was nearly 80 kilometers wide. The deposits left by these great glaciers have all the characteristics of ice-sheet deposits. They are thin sheets of till bordered by thicker ridges (the terminal moraines) and skirted on the outside by extensive outwash plains. They are even accompanied in central Washington by deposits of loess, which there furnish a valuable soil for the culture of wheat.

Terrestrial Deposits outside of the Glaciated Region.

Southern and Southeastern United States. The terrestrial formations of Quaternary age in this part of the country consist largely of river-laid sediments. They include the alluvium of the present flood-plains of the streams, and deposits which lie upon terraces along the present streams or in old valleys which have been abandoned in the process of drainage adjustment. Along the Atlantic slope the deposits of sand and clay are generally called the Columbia formation. It is not to be understood, however, that they form a continuous layer, as do most geological terranes, for they are largely confined to valleys. Furthermore, the older parts of the formation lie on the higher terraces, while the younger parts are found on lower benches. Near the broad estuaries they pass into brackish-water or marine clays and sands. Along the Mississippi River a thick blanket of these river-laid sands and silts covers all of the older formations up to the mouth of the Ohio river. They rest generally upon the Lafayette (Pliocene?) formation and consist of similar materials.

In the Great Plains, and on benches along the border of the Rocky Mountains, other subaerial gravels, sands, and loams are found at various elevations from the present flood-plains of the streams up to the tops of table-like hills. In the mountains some of these are 300 to 700 meters above the present streams. As interpreted by Davis[1] and Johnson[2] these deposits are all of Quaternary age and represent periods of drouth and excessiv sedimentation separated by times of greater humidity with consequent increase in erosion. The sediments are indistinguishable from others believed to be of late Tertiary age. In fact, the Quaternary formations, in all of the region outside of the territory covered by the ice sheets, differ in no essential respect from those of the Tertiary.

Western Mountains and Plateaus. Quaternary formations essentially like those of the Tertiary are found thruout the Rocky Mountains and plateaus. They consist generally of intermontane basin deposits and alluvial material accumulated along valleys. In many localities in Utah and Nevada temporary lakes of great extent became sites for the deposition of lacustrin silt and sand, which are now found as lake plains with accompanying shore line embankments. Since these lakes underwent fluctuations of volume and were at times strongly saline, the deposits are associated here and there with beds of salt, gypsum, and more rarely of borax.

Quaternary volcanic formations are less common than those of Tertiary age, but yet are by no means rare. Isolated craters with their attendant lava flows and beds of ash have been found in central Arizona, in the bed of old Lake Bonneville in Utah, around Mono Lake in California, and elsewhere. There is evidence that some of these eruptions were very recent,—surely post-glacial. In Yellowstone Park the Tertiary volcanic activity continued into the Pleistocene. Basalt and rhyolite flows are the result. In passing, one should mention the extensiv deposits of travertine and siliceous sinter,

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[1] Davis, W. M., The Fresh-water Tertiary Formations of the Rocky Mountain Region. Proc. Am. Acad. Arts and Sci., vol. XXXV, pp. 345—373, 1900.

[2] Johnson, W. D., The High Plains and their Utilization. U. S. Geol. Survey, Ann. Rep. 21, Pt. 4, pp. 601—741, 1901.

which have been and are still being made by the hot springs and geysers of that remarkable region.

Another center of Quaternary volcanic activity stretches from northern California north to the Canadian boundary. Pleistocene flows of basalt, andesite, and rhyolite cover large areas in northeastern California and western Oregon as well as around the great volcanic cones of which Mts. Shasta, Hood and Rainier serve as types. One of the most recent flows from Mt. Shasta is now found as a tongue of andesite, which extends southwestward nearly 80 kilometers along the Sacramento River. It has been trencht by the river and partly avoided by it. Still more recent flows may be found in the vicinity of Mts. Hood and St. Helena. DILLER[1] has made known the little cone and lava flow near Lassen Peak, California, due apparently to an eruption which occurred not more than 200 years ago.

III. Outline of Geologic History.

Archeozoic Era.

Archean period.

In the United States, as in other lands, the events of the Archean period are usually not deciphered with confidence. The record has suffered so extensivly at the hands of metamorphism and other destructiv processes that but few intelligible fragments remain.

In the districts which have been most carefully studied the oldest rocks are chiefly basic igneous masses which appear to have been extrusiv flows and breccias, and from the ellipsiodal structure which is locally common among them, some of the flows are thought to have been submarine. Rocks of this character are known in the Lake Superior region and in the Rocky Mountains. These lavas record, as the earliest events now known for North America, volcanic eruptions over wide areas. In the Vermilion range of Minnesota the lavas are associated with jaspery slates and iron ore, which appear to be interbedded with the flows. These are the only sedimentary beds known in the unquestioned Archean of the United States, and they serve merely to show that the processes of sedimentation were then in progress.

The ancient greenstones have been intruded by later igneous rocks in the form of dikes, stocks and batholiths. The intrusions were successiv, and, altho some are doubtless later than Archean, many are definitly known to be pre-Algonkian.

The dim story of the Archean seems to be largely one of many volcanic eruptions of both basic and acid rocks, with sedimentation in the intervening epochs. That there were successiv orogenic disturbances is indicated by different degrees of deformation of different parts of the mass; but it is probable that there were fewer of these disturbances in the recorded part of the period than has been commonly supposed.

Proterozoic Era.

Algonkian period.

In regions where the pre-Cambrian rocks are well known the Algonkian period seems to have been preceded by prolonged erosion, which resulted in the uncovering of deeply buried and generally much folded Archean rocks. During the Proterozoic era, sedimentation seems to have been relativly more important than in the Archeozoic,

[1] DILLER, J. S., Lassen Peak, California, folio (No. 15). Geol. Atlas of U. S., U. S. Geol. Survey, 1895.

inasmuch as the known rocks are largely quartzite, slate and dolomite. The character of the rocks is such as to indicate that the processes were similar in most respects to those now operative. Ordinary marine conditions seem to be signified by the limestone-bearing Grenville series of eastern Canada and New York, while terrestrial deposition under a climate which was not moist is indicated by the Keweenawan red sandstones of Michigan. The deposition of Algonkian sediments was interrupted by intervals of emergence during which the previous deposits were deeply eroded. The correlation of these periods of terrestrial denudation in different parts of the continent has not yet been accomplisht.

Volcanic activity, altho seemingly less important than in the Archeozoic, still continued intermittently in some parts of the country. In the Lake Superior district eruptions of basic lava took place during the Huronian period and on a much larger scale near the close of the Algonkian. In the western part of the United States, however, there is but little evidence of volcanic activity in the later portion of the Proterozoic era.

The Proterozoic rocks are now generally much folded, and it is evident that there were several distinct epochs of folding within the Proterozoic era. In northeastern Minnesota the earlier Huronian sediments were closely folded before the deposition of the Animikean (Upper Huronian) strata; and the latter have never been greatly disturbed in that region. In Michigan, on the other hand, the chief orogenic activity seems to have taken place later in the Algonkian period, after the deposition of the Keweenawan system. In western United States there is a clear record of one episode of strong folding before and another moderate or very mild disturbance soon after the deposition of the late Proterozoic sediments.

As to the climate of the United States in the Proterozoic era but little is definitly known. The barren red sandstones of northern Michigan are probably to be interpreted as evidence of relativly dry climate; and Barrell[1] has shown that the Belt series of Montana and its extensions southward indicate a semi-arid or at least seasonally dry climate.

The conditions of life in the Proterozoic era are even less definitly known. This may be ascribed partly to the fact that most of the older Algonkian formations are highly metamorphosed, and partly also to the prevalence of what are believed to be continental sediments among the less altered formations of the Protorozoic group. The presence of large beds of graphite and limonite suggests the existence of organisms in abundance, and Chamberlin[2] regards the clay-shales and limestone (both products of complete chemical decay) as further evidence that the lands were clothed with vegetation. Of definitly recognized fossil remains very few have been found in the United States. There are some problematical brachiopod-like shells from the Grand Canyon series, markings resembling worm trails, etc., and fragments described by Walcott[3] as parts of a Eurypterid *(Beltina Danai)*.

Paleozoic Era.

Post-Algonkian interval.

During the interval between the generally recognized parts of the Proterozoic and Paleozoic eras nearly all of the United States was subjected to prolonged erosion. It is believed that large areas were thus reduced to the condition of peneplains. It is possible

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[1] Barrell, Jos., Relative Geological Importance of Continental, Littoral, and Marine Sedimentation. Jour. Geol. vol. 14, pp. 316—356, 430—457, 524—568, 1906.

[2] Chamberlin, T. C. and Salisbury, R. D., Geology, Vol. II, 1905.

[3] Walcott, C. D., Pre-Cambrian Fossiliferous Formations. Bull. Geol. Soc. Am. vol. 10, pp. 199—244, 1899.

that, in some places, such as the southern Appalachian region, eastern California and western Montana, sedimentation may have proceeded continuously thru the interval; but generally the evidence of erosion is clear. That this erosion was both deep and pervasiv is shown by the fact that the thick Algonkian formations were completely removed from wide areas which they doubtless covered originally. These facts indicate that the continent at the opening of the Paleozoic era was largely land, perhaps even more emergent than now. It also bears witness to a prolonged period of quiet during which no considerable orogenic disturbances interfered with the extension of graded plains.

Cambrian period.

The first appearance of the *Olenellus* fauna has been arbitrarily taken as marking the beginning of the Cambrian period. Clearly the chief geographic change of the period was the slow invasion of the United States by the oceans on the east and west. In the early part of the Cambrian period two geosynclines seem to have been submerged, —one in the California-Utah-Montana region, and the other marking the site of the Appalachian Mountains. During the rest of the period the sea spread gradually from these depressions, and doubtless also from the ocean basins, so that in the middle Cambrian the land was less extensiv, and in the upper Cambrian nearly all of the United States was submerged. The only parts of the country which it is believed may have remained above the sea were small districts along the northern border from Minnesota to New York. The condition of the continental border on the east and west is unknown. As the sea advanced, the zones of sedimentation migrated with it, so that the base is markt nearly everywhere by a continuous sandy formation which is, however, not everywhere of the same age. Some parts of this were probably deposited on land surfaces.

Thruout the Cambrian period the United States seems to have been free from disturbances both orogenic and volcanic, except perhaps in Maine.

The Cambrian life of the United States is far better known than the biota of the Algonkian period. The marine faunas of the sandy, muddy and calcareous bottoms are all tolerably well represented. Among these faunas it is possible to recognize a progression in time so that lower, middle and upper Cambrian assemblages are discriminated. There is also considerable evidence of the existence of several marine provinces of life; (a) the New England province, (b) the Appalachian and interior province, and (c) the Cordilleran province. Almost no traces of land animals or plants have been found in the Cambrian rocks of the United States, altho there is indirect evidence in the character of the sediments themselves that such life was abundant.

But little progress has been made toward interpreting the Cambrian climate of the United States. It is safe to assume, however, that in the later part of the period the broad extension of the sea favored an equable oceanic climate. Within the area of the United States indications of deserts, glaciers and other results of climatic extremes are lacking.

Ordovician period.

As generally limited, the Ordovician period does not closely fit the geologic history of North America, inasmuch as its limits do not seem to coincide with the greater geographic changes. For this reason Schuchert[1] has lately advised a redivision of the early Paleozoic times.

In a large way the Ordovician period was characterized by a widespread submergence of the United States, culminating in the middle of the period and

[1] Schuchert, Chas., Paleogeography of N. A., Bull. Geol. Soc. Am., Vol. 20, pp. 427—606, 1910.

abating toward the close. In detail, however, this change was not simple. The widespread unconformity between the lower Ordovician formations and the Chazy beds of the eastern states shows that the sea withdrew from much of the United States early in the period. This change was not accompanied by perceptible deformation. After this temporary submergence the sea re-advanced and, at the time the Trenton limestone was deposited in eastern United States, the maximum submergence was reached. In nearly all parts of the United States where rocks of this epoch are known they contain but little clastic material,—a fact which is interpreted to mean that the lands were low as well as small. It is hardly to be doubted that the middle Ordovician submergence was the greatest which the United States has undergone in recorded geologic history. With such widespread seas and free communication, the middle Ordovician faunas had a nearly universal distribution within this country, and show intimate relationships with those of other continents.

The shaly formations, such as the Utica in eastern United States, indicate a recession of the shores and this seems to be confirmed by the finding of a widespread altho obscure unconformity in the Mississippi valley and eastern states, and perhaps as far west as the Rocky Mountains. Following this recession of the sea another wide submergence almost as great as the preceding is indicated by the broad distribution of the shales and calcareous beds which contain the Richmond fauna. The prevalence of muddy sediments and in the East even of sandy material at this horizon is believed to reflect the orogenic disturbance which marks the close of the Ordovician period in eastern North America. From New England south to Virginia and doubtless beyond, the Ordovician and all older rocks were at this time intensely folded, so that many of the beds were converted into schist and gneiss. That the disturbance occurred at or near the close of the Ordovician is indicated by the fact that the Silurian rocks lie in markt unconformity upon the eroded edges of the older beds. The arena of this disturbance was sharply limited on the west; for altho the rocks east of the Hudson River are highly folded, those immediately west of it were but little disturbed.

In United States there is no definit evidence of volcanic activity in the Ordovician period, unless it be in California on the Pacific coast, where rhyolite of unknown age lies beneath Silurian strata.

Silurian (Gothlandian) period.

The most important general event of the Silurian period in the United States was the re-submergence of the country. The lack of a demonstrated unconformity between the Ordovician and Silurian in the western states suggests that there was continual submergence there. In the eastern states, however, there is sufficient evidence that the sea had withdrawn and now slowly re-advanced. The most conspicuous land mass seems to have been that erected by the Taconic folding, which extended from New England southwestward perhaps to the Gulf region. The conglomerate, coarse sandstone and shale which form the base of the Silurian along the Appalachian mountains and thin out westward into Ohio and Indiana doubtless mark the rapid erosion of this land. These clastic deposits are largely devoid of fossils and are believed to be chiefly continental in origin.

The Silurian limestone of the Mississippi valley extends eastward to New York and Virginia, but seems to lie at much higher horizons there than in Illinois, as if clear water conditions did not become possible in the East until much later in the Silurian period. In the clear and doubtless relativly shallow sea which the limestone indicates, coral reefs of considerable thickness have been found, and with them an abundance of other fossils. At the time of its greatest extension the Silurian sea may have covered all of the United States except the eastern land mass (Appalachia),

some points near the Pacific coast, and not improbably some others along the present Rocky Mountains.

The uncertainty of the Paleozoic history of the western states is due largely to the deficiency of fossils and the general lack of detailed investigation.

In this broad sea flourisht a cosmopolitan fauna closely related to that of Europe. The route of intermigration seems to have been by way of Alaska and probably also along the Arctic islands.

Parallel to the Appalachian Mountains the Clinton iron ore formation, which separates the older clastic Silurian rocks from the mid-Silurian limestone, bespeaks unusual marine conditions. Burchard[1] finds evidence that these deposits were laid down in shallow bays close to shore, but the precise cause of the ferruginous deposits is still unknown.

The record of the later part of the Silurian period shows that the condition of eastern United States was radically changed, but without a corresponding change in the western mountain region. In the district surrounding Lake Ontario and extending into adjacent states, red shales with beds of gypsum and salt imply the temporary exclusion of the sea from that region, and the deposition of sediments under an arid climate. Above and below the salt-bearing series, limestones and shales contain peculiar fossils which probably dwelt in fresh water. In the Mississippi valley and the southwestern interior states, these terrestrial deposits are missing, their place being taken by a widespread altho obscure unconformity which doubtless records an emergence of the central portion of the United States during the late Silurian. The peculiar geographic and topographic conditions which seem to be necessary for the production of a local desert climate are still imperfectly understood. Unless there is evidence of general aridity over the temperate regions of the globe, it is probably necessary to assume that the desert conditions were due to a widely extended land and perhaps to barrier mountain ranges favorably situated in eastern and southern United States. There is some independent evidence that such ranges existed earlier in the Silurian.

As generally constituted, the Silurian period ended in eastern United States with a return of the epicontinental sea and the subsequent disappearance of the desert conditions of the Salina (Cayugan) epoch. This inundation is recorded in the calcareous sediments of the Monroe series of Michigan and the Cobbleskill of New York. Between these beds and the overlying Devonian limestones there appears to be no important physical break. In western United States from Utah and Montana to California the plane of division is even less distinct. In the central interior and portions of the Rocky Mountain states, however, the general unconformity above mentioned seems to indicate that the interior region remained as low land feebly eroded during the late Silurian and early Devonian.

There is no clear record of folding or faulting in the United States during the Silurian period, altho such movements not improbably took place in the extreme northeastern states. Volcanic activity was confined, so far as the record indicates, to the Pacific and Atlantic coasts. In Maine particularly the eruptions produced thick beds of pyroclastic material with lava flows, thought to belong chiefly to the early part of the period.

Devonian period.

The passage of the Silurian into the Devonian period, — as those periods are commonly limited, — seems to have been markt in the United States by no important geographic changes. The central portion of the country remained above sea level thru much of

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[1] Burchard, E. F., Iron Ores, Fuels & Fluxes of the Birmingham District, Ala., U. S. Geol. Surv. Bulletin 400, pp. 39—41.

early Devonian time, but near the western and eastern coasts intermittent submergence is believed to have been in progress. The separation of these two seas is indicated by the entire lack of harmony between the early Devonian faunas of the East and West. There is even considerable evidence to show that there were three provinces, the third in the lower Mississippi valley having been inhabited by a fauna with Brazilian relationships. The widespread limestones and the thin shales of the early Devonian formations in both eastern and western United States are generally interpreted to mean shallow seas bordered by low forested lands which were not subject to rapid erosion. Among the shales, black bituminous varieties predominate in the eastern states. They were evidently deposited very slowly under peculiar conditions which were unfavorable to life.

As the Devonian period advanced, a general expansiv tendency is observable in the seas. Thus late Devonian sediments lie upon much older rocks in Colorado, and middle Devonian rocks rest unconformably upon the Silurian in Illinois. One result of the slow expanding of the bay-like arms of the sea, which seems to have characterized the early Devonian, was the coalescence of marine faunal provinces, allowing the mingling of once isolated faunas to such an extent that in the later Devonian rocks a single great cosmopolitan fauna allied with that of Europe and Asia is found in nearly all parts of the United States.

Altho the deposition of calcareous sediments continued in the western states thruout the Devonian, the later part of the period was characterized in the Appalachian region by the rapid accumulation of sands and muds until finally they reached great thickness. The Catskill and associated formations are generally devoid of fossils, and among the few which have been found the commonest are fishes, plants and mollusks, all of which may be of fresh water habit. The facts suggest that the climate was semi-arid and that the deposits were spread by shifting rivers on a coastal plain. This rapid deposition of clastic materials in the East may have been coincident with an orogenic disturbance in the New England states, for there is evidence of folding in Maine and eastern Canada at some time about the middle of the Devonian.

Thruout most of the United States there is no sharp line of demarcation between the Devonian and the overlying Mississippian system. This shows that the expanded sea of the Devonian suffered no material change, the one period there graduating into the next. For this country, indeed, the Devonian and Mississippian could well be combined as one period.

Thruout the United States there is a general lack of volcanic rocks of Devonian age. Aside from certain flows in the Sierra Nevada mountains of California and some Devonian eruptivs in Maine there seems to be no record of volcanic activity in the United States.

Mississippian period.

During the quiet continuation of marine conditions from the Devonian into the Mississippian periods, limestone was the prevailing deposit over the central and western states. There may well have been some island-like lands in Colorado and Wyoming, for the Mississippian and even Pennsylvanian sediments generally rest upon older rocks. Around the borders of the epicontinental sea in California on the one hand and in the Appalachian region on the other, clastic sediments like those of the Devonian were laid down also in the Mississippian period. The eastern sands and shales extend westward into Michigan and Indiana, where they interleave with the limestones of the central interior, and much farther southwest into Arkansas and Oklahoma, indicating the existence of a considerable land mass to the south as well as to the east.

The clear sea of the central Mississippi valley states was inhabited by hosts of crinoids, blastoids and many other marine animals. In the coarser clastic deposits of

the East, marine fossils become scarce, and Barrell interprets the Mississippian system in Pennsylvania as a piedmont deposit made under a semi-arid climate,—in short, a continuation of the Catskill conditions of the late Devonian. A different fauna consisting largely of brachiopods and corals inhabited the sea in Utah, Montana and adjacent states, where dark and even sulfurous limestone was deposited. Many details of faunal migrations thru the interior states have been worked out by Ulrich, Schuchert, Weller and others, but agreement as to many of the conclusions is still lacking.

The period closed with a retreat of the sea from the interior of North America, as indicated by the widespread unconformity at the base of the overlying Pennsylvanian system. This unconformity is traceable from Pennsylvania to Utah and from Alabama to Arizona. The emergence is not known to have affected the Pacific coast and perhaps not the Oklahoman region. Like the earlier emergences which have been mentioned, this seems not to have been attended by much deformation, and the contiguous beds are nearly parallel in structure. In the central states, however, there seems to have been more deformation at this time than at any other in the Paleozoic era. In Missouri, Illinois and other states very low folds in the Mississippian limestone are truncated by the Pennsylvanian beds above; at some points in northern Illinois the Pennsylvanian strata overlap all older formations down to the early Ordovician.

With the close of the Mississippian there was also in the United States a striking change in the marine faunas. Many groups hitherto prominent disappear, among them the camerate crinoids, the blastoids, and the already senile group of cystids.

Pennsylvanian period.

Altho the Pennsylvanian is generally combined with the preceding period, it is now coming to be recognized that so far as the United States is concerned, it is more sharply markt off from the Mississippian than from the Permian. A more appropriate classification would therefore be Devono-Mississippian and Anthracolithic (Pennsylvanian-Permian). The ancient land mass of Appalachia still persisted in the East, but signs of the permanent emergence of the eastern interior region began to appear. The alternating sandstone, shale, and coal of the Coal Measures, are believed to record the existence of low swampy coastal plains subject to local advances and retreats of the shore line, bringing now submergence and at other times erosion. The climate must have been moist, and there is much to indicate that it was cool rather than tropical. In the low grounds, at least, there were forests of ferns and other pteridophytes and large numbers of ancestral gymnosperms *(Cycadofilicales)*. These lowlands and swamps were inhabited by a variety of primitiv insects, amphibians and the earliest true reptils.

West of the area within which the Coal Measures were being deposited, from Michigan and Indiana to Kansas and Oklahoma, the sea was more permanent, as evidenced by the thickness of fossiliferous shale and limestone with only occasional beds of coal and sandstone. Brachiopods, crinoids and many other ordinary marine fossils were there abundant.

In the western mountains the prevalence of limestone in the Pennsylvanian system indicates submergence beneath the open sea. That there were, however, land masses in the Rocky Mountains, especially in Colorado, is implied by the red conglomerates and sandstone, some beds of which contain disseminated gypsum. The composition of these sediments seems to imply a tolerably arid climate unlike that with which the eastern interior region was favored. Over much of Wyoming and Montana sandy sediments were deposited both on land and in the shallow sea, the one condition apparently alternating with the other in some localities.

The marine faunas of the West are distinctly Asiatic in their relationships, being characterized by such familiar foraminifers as *Fusulina* and *Schwagerina*.

In the United States no prominent physical event serves to distinguish the Pennsylvanian from the Permian period. It is evident, however, that during the earlier period the sea had begun the slow retreat which was to culminate near the close. It is because of this gentle gradation of one period into the other that in the United States there has been so much dispute as to just where the boundary should be drawn.

Permian period.

One dominating tendency characterizes the Permian in North America as in other continents, namely, an expansion of the dry lands. The early Permian fresh-water sediments near the headwaters of the Ohio River indicate that the sea had already withdrawn from that portion of the United States. In Kansas and Texas the epicontinental sea lingered on into the Permian, as evidenced by the marine faunas which are generally correlated with the Artinsk stage of Russia.[1] Even there, however, the later Permian red beds with seams of gypsum show that the region had emerged. Only in western Texas does the sea appear to have remained after the early part of the period. The varied altho somewhat dwarfed fauna of the Guadalupian series is distinctly Asiatic in character and is correlated with the Gschelian of Russia.[2] By the close of the period, it is probable that all of the United States was land, except a bay in the northwestern states stretching from California and Oregon east to Utah.

In the region of the Rocky Mountains and Great Plains, an arid climate is implied by the prevalent red beds with their saline lake deposits. In these continental sediments, fossils of all kinds are rare,—as might be expected. On the southern border of the red bed outcrop in Texas and Oklahoma, many reptils and robust amphibians have been found and described by Cope, Williston and others. Most of them seem to have been land-inhabiting animals with only remote and doubtful relationships with the early vertebrates of Europe and Gondwanaland.

In addition to the great extension of the continental land, probably exceeded at but few times in geologic history, the close of the Permian in the United States is markt by the folding of the Paleozoic sediments along the Appalachian Mountains. This disturbance is thought to have originated in the Atlantic ocean basin, all the folds and overthrusts being therefore projected northwestward. It affected a belt 200—300 kilometers wide from Maine to Alabama. One of the peculiarities of this disturbance is that it was accompanied by volcanic activity only along the eastern side of the deformed region. The result was doubtless a great system of parallel mountain ranges much higher than their modern descendents. On purely stratigraphic evidence it is difficult to determine the time of the Appalachian folding, since in eastern United States there are no strata of ages between early Permian and late Triassic. Orogenic disturbances are, however, almost always accompanied by markt geographic changes, especially by emergences of the continents; and so the folding may be supposed to have taken place near the end of the Permian, when the emergence of North America reached its maximum.

In western United States the close of the Permian was not markt by deformation, except perhaps in California; so far as known, the activities of the Permian past on almost without interruption into the Triassic. Even where there is an unconformity it is generally inconspicuous and separates similar beds.

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[1] Girty, G. H., The Guadalupian Fauna, U. S. Geol. Survey Prof. Paper 58, 1908.

[2] Prosser, C. S., Revised Classification of the Upper Paleozoic formations of Kansas, Jour. of Geol., Vol. 10, 1902, pp. 703—737; and, The Anthracolithic or upper Paleozoic rocks of Kansas and related regions. Jour. of Geol., Vol. 18, 1910, pp. 125—161.

Mesozoic Era.

Triassic period.

The changes of the Permian left almost all of the area of the United States above the sea and bordered on the east by a chain of young mountains, which were doubtless rugged. The events of the East center chiefly around the erosion of these mountains. West of the Appalachian mountain system, there may have stretched a broad plateau, for all of the Triassic deposits, which must have been strewn over the western piedmont slopes from New York to Alabama, have been removed without leaving any trace. East of the divide, broad intermontane valleys afforded sites for the deposition of the Newark series. These thick deposits of sediments, containing much that is ill-assorted and coarse, were probably laid down somewhat rapidly by streams. There is reason to believe that the climate was intermediate between moist and arid, or at least that there were prolonged dry seasons. Occasional volcanic eruptions are indicated by the sills and flows of diabase interbedded with the sediments. These intermontane tracts were inhabited by dinosaurs and early crocodiles, and in Virginia there have been found the problematical fossils long regarded as being the earliest mammals (*Dromatherium*, etc.). According to current correlations, the Newark sediments were laid down late in the Triassic period. If this is correct, the earlier epochs have left no record in the sediments.

The broad interior region of the United States east of the Rocky Mountains is devoid of Triassic rocks, and probably was land. In the Rocky Mountains and plateau region saline lakes and sedimentation under a dry climate seem to be clearly indicated by the gypsiferous red beds which are in most respects like those of the Permian beneath. That the country was not, however, an absolute desert is indicated by the massiv tree trunks and dinosaur bones found imbedded in the Triassic red beds of Arizona.

On the Pacific coast the ocean extended farther east than now. Early in the Triassic period it still lingered as far as southeastern Idaho, harboring in that region a cephalopod fauna which has close relations with that of the Indo-Siberian region. This eastward extension seems to have been soon restricted to the Pacific coast states; they, however, remained submerged thruout the period. In California, and probably northward, there were volcanic eruptions chiefly of the explosiv type, but it is not apparent that these disturbances were more prominent in the Trias than in some earlier periods in the same region.

Jurassic period.

At the opening of the Jurassic period the United States was very largely in the condition of land, as it was in the Triassic. Only a narrow strip along the Pacific coast seems to have been submerged.

About the beginning of the period, the Atlantic coastal region,—on which lay the Newark series of late Triassic age,—was warpt and broken into a series of blocks separated by normal faults. It may be supposed that this temporarily produced a series of asymmetrical ridges with escarpments. By the end of the period, however, the progressiv denudation of the Atlantic highlands is believed to have resulted in a general base-levelling of that part of the United States. Upon the widespread peneplain, there were left standing numerous residual hills of which the largest were probably integrated ranges of considerable size in the Carolinas.

The record of events in the central and western states is meager, but, such as it is, seems to indicate a continuance of the land condition with local sedimentation in a dry climate, as in the preceding period. The Colorado Plateau appears to have

been a sandy desert.[1] On the Pacific coast marine strata with lower, middle and upper Jurassic fossils allied to those of Europe indicate the submergence of parts of California and adjacent states, with the coast line shifting considerably during the period. About the close of the middle Jurassic, a broad shallow gulf entered the Rocky Mountain region from the north. It spread southward to Colorado and southwestward as far as Utah, but appears not to have been joined to the Pacific ocean across any part of the United States. The sediments are generally fine and relativly thin, except along the western border of the trough. The fossils in these beds are boreal in their relationships indicating a connection with Alaska and Siberia. This Rocky Mountain gulf seems to have disappeared before the close of the Jurassic and on its site the fresh water sediments of the Morrison formation were deposited. These have often been described as lacustrin, but it is probable that sluggish rivers were largely concerned in their making. The Morrison formation has been referred to both Jurassic and Comanchean systems, and it may well be considered as representing a transition from the one period into the other. With their gray, black and yellow colors, the Morrison beds indicate a moister climate than that of the Permo-Triassic of the same region. The same implications are supported by the finding of abundant remains of cycads and a wonderful variety of dinosaurs. It must have been a region in which vegetation flourisht.

Late in the Jurassic period a bay seems to have extended from Mexico up into western Texas. In this was deposited the Malone formation, the marine fossils of which find their nearest relativs in the upper Jurassic rocks of Mexico.

At or near the close of the Jurassic period there occurred another of the shor epochs of intense deformation which periodically affect the borders of continents. At this time the Jurassic and older rocks along the Pacific slope were closely folded and invaded by great masses of granitic magma which locally metamorphosed the surrounding sediments into schists. There is evidence that this disturbance extended from Canada to Mexico and one of its results must have been the production of a series of mountain ranges of which the present Sierra-Cascade system is a successor. Since the Comanchean beds lie unconformably upon the deeply truncated edges of the Jurassic rocks it is evident that the folding was completed and succeeded by effectiv erosion before the Comanchean period was far advanced. No corresponding disturbances have been noted in other parts of the United States; there, on the contrary, the Jurassic period past into the Comanchean with but slight interruption or by imperceptible gradation.

Comanchean period.

The folding of the rocks along the Pacific slope marks off the Comanchean from the Jurassic period more distinctly than usual. Its separation from the succeeding Cretaceous is less readily made.

One of the chief events of the Comanchean was the beginning of the formation of the coastal plain which borders the Atlantic and Gulf coasts of the United States. It is possible that the oldest beds were laid down in the Jurassic period, but present evidence seems to favor the Comanchean. The deposition of these basal sediments does not imply submergence of the eastern border of the continent, for they are fresh-water beds. They seem to record the earliest appearance of the angiosperm plants, which made great progress during the Comanchean period. Bones of dinosaurs and walking turtles give further evidence of land conditions.

On the western border of the continent, the erosion of the Sierra-Cascade uplift doubtless proceeded thruout the period. This activity is reflected apparently in the

[1] Huntington, E., & Goldthwaite, J. W., The Hurricane fault in the Toquerville district, Utah, Harv. Coll., Mus. Comp. Zool. Bull., Vol. 42, 1904.

enormous thickness of clastic sediments in the Comanchean system from California to Washington. These beds are partly marine but may well be in large part terrestrial in origin. In so far as marine, they were deposited very near shore. Their marine fossils indicate freedom of connection with Alaskan and Siberian countries early in the period, but later with the Indo-Japanese region. This may record climatic changes within the period.

In the broad shallow depression occupying the site of the present Rocky Mountains the deposition of continental sediments probably by rivers and lakes continued from the Jurassic thru the Comanchean. Occasional coal seams and the remains of cycads and dinosaurs show that the moderate climate of the Jurassic persisted without notable change. In the varied assemblage of dinosaurs there are many types which closely resemble those of western Europe.

This central western region seems to have shelved off southward into the Gulf of Mexico. During the period, that sea slowly invaded the Texas region and at its maximum stage advanced as far as western Kansas. Around its edges were deposited muds and sands which grade into the terrestrial sediments farther north; while out to sea in clearer water thick beds of chalk with corals and other strictly marine animals accumulated. The faunas of this expanded Gulf of Mexico find their nearest relativs in the Spanish peninsula of Europe, but have nothing in common with the contemporaneous Californian life.

At the close of the Comanchean period, a general emergence of the continent without notable deformation is indicated by a widespread unconformity thruout the eastern and central parts of the country and locally even on the Pacific slope. In the Rocky Mountain region and California the deposition of continental sediments continued locally into the Cretaceous period, but was interrupted in other places by erosion. The record seems to indicate neither notable deformation nor volcanic activity anywhere in the United States during the Comanchean period.

Cretaceous (Upper Cretaceous) period.

The Cretaceous period in the United States was characterized by a general expansion of the sea, which was followed near the close by an equally general emergence accompanied by an important crustal disturbance.

On the eastern and southeastern sides of the country the Atlantic ocean encroached over the low coastal plain. Since the edge of the Cretaceous deposits has been cut back by erosion, the sea must have gone inland beyond the present outcrop of the formations. The prevalence of fine sediments, including much greensand on the east and chalk on the south, is in harmony with other evidence, all tending to show that the eastern states were either at or near base-level, their surface being varied only by scattered groups of monadnocks, and that they were well clothed with verdure.

On the western coast, altho the sea level may have risen relativly, it seems not to have been able to advance far inland. This fact, together with the coarser character of the Cretaceous sediments—part of which are terrestrial and part marine,—may be taken to mean that the western slope was more abrupt and rugged.

In the Rocky Mountain region and Great Plains the broad lowland, which was well markt in the preceding periods, was inundated. The advance of the shore line is probably first recorded in the non-marine Dakota formation with its abundant leaves of angiosperm trees and occasional thin coal seams. Before the middle of the period the waters of the Arctic ocean and the Gulf of Mexico seem to have joined along this downwarp, leaving a long narrow western land and a triangular eastern continent. The Coloradoan sea was 1700—1800 kilometers wide at its maximum expansion. The prevalence of chalk in the central portion indicates clear water, which is known to have been inhabited by a varied marine fauna dominated by mosasaurs and toothed

birds. Nearer the shores both east and west, however, muds and sands accumulated, and these also lie both above and below the chalk. Along the western shore of the sea, fresh-water sediments with coal seams probably mark the existence of swampy coastal plains. There are some traces of similar conditions also in Minnesota on the east. The marine faunas of this western sea are closely related to those of the Atlantic coastal plain, but are quite distinct from those of the Pacific coast, which have Asiatic affinities. The distinctness is ascribed to the persistence of the elongate western land mass which prevented free migration of the marine life. The thick series of fresh water beds with coal seams which overlies the marine strata in the Rocky Mountain region doubtless records the recession of the interior sea and the complementary southward advance of swampy river plains. This low land was clad with vegetation having close relationships with the Eocene flora, but was inhabited on the other hand by a typical Mesozoic assemblage of vertebrates including primitiv non-placental mammals and the last of the great dinosaurs. Among the latter the *Ceratopsia* with their rhinoceros-like horns were conspicuous.

At the close of the Cretaceous period the sea was almost entirely withdrawn from the United States, as indicated by the unconformity which, altho obscure, is general along the eastern and southern coastal plains and in the western interior region. On the Pacific coast the evidence of emergence is not so clear and consists in the partial substitution of fresh water sediments for marine, rather than in a definit unconformity. In the eastern states the Cretaceous peneplain is said to have been warpt at this time, with the result that the softer rocks have since been etched out leaving the hard layers protruding in relief. This uplift amounted generally to 500—1000 meters.

In the Rocky Mountains the close of the period is markt by the so-called "Laramide Revolution",—the deformation which produced the Rocky Mountain folds. Over a broad strip including the states of New Mexico, Colorado, Wyoming, Montana and parts of adjacent states, the older rocks were deformed. Evidence now accumulating tends to show that there were really two and perhaps more episodes of folding: one at the close of the Cretaceous, and one early in the Eocene period, just after the deposition of the Fort Union (Paleocene) formation. As compared with the Appalachian and Sierran folds those of the Rocky Mountains are relativly simple and open. In most places they are merely low arches and basins. On the northwestern side of the region, from Utah to Montana, sharp folds and even large overthrusts were produced. The folding was accompanied by widespread volcanic activity, building many cones, whose existence is now recorded in thick beds of tuff and breccia with lava flows. The volcanic eruptions extended far outside the area affected by the folding, southeast as far as Texas and perhaps to the Mississippi River in Arkansas.

Cenozoic Era.

Eocene period.[1]

By Eocene time the United States had acquired its present general outline, with the exception of the peninsula of Florida and some smaller features. The Atlantic and Gulf coasts were partly submerged and a long bay extended up the Mississippi valley almost to the Ohio River. On the Pacific coast, likewise, the ocean spread inland to the base of the Sierra Nevada.

[1] The division of the whole Tertiary period into Eocene, Oligocene, Miocene and Pliocene is not well adapted to show the geologic events in the United States. Basing the divisions on diastrophic disturbance, a two-fold classification would be more servisable. For the sake of uniformity, however, in comparison with other countries, the four-fold division is here retained.

Along the Atlantic coast the Eocene sediments are so much like those of the Cretaceous that one may believe the conditions during the two periods were similar. Along the Gulf border terrestrial sediments, including coal seams, are somewhat more prominent; and in Texas there are even local beds of gypsum, signifying at least temporary aridity. The terrestrial deposits, such as the so-called "Lignitic" formation are best developed along the border of the older land, and near the base of the system, while toward the Gulf of Mexico marine sediments predominate. Along the Pacific coast deposition was local. In California it was largely in marine waters of bays, but in Oregon and Washington the sediments are chiefly of fresh-water origin and include many coal seams. The Puget formation of Washington records rapid sedimentation in a broad depression not occupied by the sea, and under a climate apparently as moist as that of the present, altho probably warmer.

In the Rocky Mountains and adjacent regions of the West, denudation of the newly uplifted folds was in progress. Before the middle of the Eocene period they had been truncated and the whole area reduced to a topography which was probably much less mountainous than the present, altho not flat. The complement of this denudation is found in deposits laid down in many local basins and out upon the low plains to the east, especially in Montana. It was formerly thought that all of these were of lacustrin origin, but the newer interpretation [1] assigns them largely to the work of aggrading streams, with lakes and marshes as subordinate features. This hilly or mountainous region with its open alluvial basins enjoyed a climate sufficiently moist and warm to permit the growth of luxuriant vegetation, among which palms, figs, and other semi-tropical plants were prominent. At the same time the region is known to have been inhabited by a wonderful variety of mammals, the rapid evolution of which has been workt out by means of the wealth of fossils found in the intermontane deposits. The first, or Puerco-Fort Union (Paleocene) fauna was extremely primitiv, and is regarded by Osborn[2] as a lingering remnant of the Mesozoic fauna, with some South American affinities. There quickly appeared, however, a much more advanced assemblage of eutherian mammals, so much like those of western Europe that it has been said the faunal connection between the two continents was never closer than at that time. Toward the close of the Eocene the mammal faunas of western United States became somewhat more provincial, probably because of temporary isolation.

The volcanic eruptions which were widespread at the beginning of the period continued apparently with less frequency thruout the Eocene. In central Washington and perhaps other regions there were extensiv fissure flows like those of the Cretaceous in India.

Oligocene period.

The close relation between the Eocene and Oligocene systems in the United States and the general similarity of the deposits indicates that the two make essentially one period. Along the Gulf border the Oligocene sediments are more largely limestone than the Eocene. On the Atlantic coast the Oligocene beds have been identified at only a few points, but it is not improbable that the formations have been removed in some places and buried in others. On the Pacific slope sediments much like those of the Eocene, altho somewhat sandy, accumulated locally in California and northward near the present coast line. The shifting sites of sedimentation and the changes in the character of the beds are taken to indicate unstable geographic conditions on the Pacific border.

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[1] Davis, W. M., Continental Deposits of the Rocky Mountain Region, Geol. Soc. Am. Bull. XI, pp. 596—601, 603—604, 1900.

[2] Osborn, H. F., Cenozoic Mammal Horizons of Western United States, U. S. Geol. Surv. Bull. 361, 1909.

In the Rocky Mountain region the chief site of sedimentation seems to have been out upon the plains along the east flank of the mountains, from South Dakota to Colorado. The White River formation has recently been interpreted as composed of loess and river-flood deposits, influenced by a somewhat drier climate than that of the Eocene. In harmony with this the fossil mammals belong to the upland running and burrowing types, with none of aquatic habit. Like the later Eocene faunas, those of the Oligocene of the West do not show close relationships with the mammals of other continents.

Local deposits of volcanic ash and lava in Colorado, Wyoming and Oregon serve to show that the volcanic disturbances of the Eocene were being continued intermittently.

That geographic changes, chiefly in the nature of emergence, were more pronounced after the close than at the beginning of the Oligocene is indicated by the fact that the Miocene and Oligocene beds are generally separated by an unconformity. It is, however, not clear that this emergence did not coincide with the well known deformation within the Miocene.

Miocene period.

The widespread deformation in the middle of the Miocene period serves generally at least to divide the period into two distinct parts. The early part is essentially a continuation of the Eocene-Oligocene, while the later is more closely bound to the Pliocene.

The record of Miocene history is clearest in California. The sea appears to have covered the present site of the Coast Ranges generally and extended almost to the base of the Sierra Nevada. The variety of sediments attests the many variations in conditions. Much of the time the sea was clear and not improbably deep, for enormous thicknesses of radiolarian and diatomaceous chert and shale form part of the early Miocene series. Incidentally, there was some volcanic activity, now recorded in thick deposits of tuff. The later Miocene sediments of California are more largely clastic, including much conglomerate, and they lie upon folded early Miocene and older beds. This unconformity records the climax of the mid-Tertiary orogenic disturbances, which were even more prominent in some other parts of the world. In the Coast Ranges the deformation went so far as to produce overthrust folds and considerable dynamic metamorphism. Its effects are traceable along the entire Pacific coast of the United States and there are clear signs of it eastward in central Oregon and Nevada. Probably during the Late Miocene epoch of sedimentation in the Coast Ranges, the older auriferous gravels of the Sierra Nevada were deposited. They seem to have been laid down in relativly wide valleys in a region, which, altho hilly, was probably far less mountainous than now.

The Atlantic and Gulf coasts of the United States were resubmerged in the Miocene, the inundation being more widespread than usual on the Atlantic coast but somewhat less so in Texas. The sediments are not unlike those of preceding periods in the same region, but the faunas indicate, according to Dall[1], a distinctly cooler climate.

In the western mountain and plateau region there are local valley and basin deposits of Miocene age. In general they are like those of early Tertiary age, altho the sediments are, on the average, of coarser texture and include much conglomerate. These fluvial and lacustrine deposits have yielded many fossil mammals, which show a further influx of types from Europe and Africa in late Miocene time. The character of both fossils and sediments is said to imply a relativly dry climate, perhaps not unlike that of the present Great Plains region. About the same time the climax of

[1] Dall, W. H., and Harris, G. W. Correlation Papers. Neocene. Bull. 84, U. S. Geol. Surv. 1892.

Tertiary volcanic activity seems to have been reacht. In the Northwest, embracing portions of Oregon, Washington and Idaho, great quantities of basalt rose to the surface, largely thru fissures, and poured out over an area equal to more than 600,000 square kilometers. Eruptions more largely of the explosiv type built cones centering around Yellowstone Park; and they were prevalent also in northern California and generally along the Cascade range. Thruout the western states there are many deposits of volcanic breccia and flows, most of which belong to this epoch. Accompanying the vulcanism there seems to have been rather general warping in the western states and probably the beginning of some of the greater faults. These disturbances do not appear, however, to have given rise to the present relief features, for most of the latter are distinctly of later age. Both the vulcanism and the warping are perhaps to be considered as but phases of the general unrest of the continent in the middle Miocene, as exprest most clearly in the folding of the Pacific border ranges.

Pliocene period.

As compared with the disturbed conditions of the later Miocene, the Pliocene period seems to have been one of relativ quiet in the United States. Evidence accumulating from the western states tends to show that the relief features produced by the Miocene orogeny were planed down during the Pliocene to peneplains in some districts and to hilly uplands in others. Davis[1] reacht this conclusion for the Grand Canyon region, Willis[2] for central Washington and Ball[3] and Blackwelder[4] for the east-central Rocky Mountains. If these interpretations are correct, the western region must have stood much lower then than now, and must have been relativly free from diastrophic changes.

Around the edges of the continent, as in earlier Tertiary times, sediments were deposited upon coastal plains. Some of these deposits were laid down in the edge of the sea and, in Florida, perhaps even far from shore; but much of the eastern Pliocene system is of fluviatil origin. The Lafayette formation of the southeastern states is believed to have been deposited by many shifting streams cooperating, at a time when the shore line was probably no farther inland than now. Locally on the Pacific coast, — particularly in central California, — clastic sediments were laid down rapidly, and before the end of the period attained a remarkable thickness.

In the inner western mountains there is but scant sedimentary record of the Pliocene. This is probably in harmony with other facts indicating a steady planation of the region. On the plains east of the mountains, local Pliocene deposits made by streams contain the remains of mammals, among which are many South American types. These invaders seem not to have appeared in the earliest Pliocene but near the middle of the period. From this it is inferred that the diastrophic changes of the Miocene in Central America did not fully provide the connection between North and South America at Panama, but that it was completed early in the Pliocene.

Evidence in the marine faunas along the coasts points to a lowering of the general temperature, especially toward the close of the Pliocene, and on the plains there is continued evidence of a relativly drier climate than that of Eocene time.

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[1] Davis, W. M., An Excursion to the Grand Canyon of the Colorado, Harv. Coll. Mus. Comp. Zool. Bull. 38, pp. 108—201, 1901.

[2] Willis, B. and Smith, G. O., Contributions to the Geology of Washington. U. S. Geol. Survey, Prof. Paper 19, 1903.

[3] Ball, S. H., Economic Geology of the Georgetown Quadrangle, Colorado. U. S. Geol. Survey, Prof. Paper 63, 1908.

[4] Blackwelder, Eliot, Cenozoic History of the Laramie Region, Wyoming. Jour. Geol. Vol. 17, 1909, pp. 429—444.

About the close of the Pliocene period there was a renewal of the warping and milder diastrophic activities, attended, however, by but little that deserves the name of folding, except on the coast of California. The western plateaus seem to have been elevated partly at this time, but the full height was attained much more recently. The warping of the Basin region was attended also by much normal faulting, making many block mountains out of Miocene lava flows in Oregon and continuing movement along fractures earlier establisht in Utah and Arizona. Most geologists now agree with J. Leconte in regarding the topography of the West as largely post-Pliocene in age; and much of it as still younger. Even in the eastern highlands there is evidence of a further rejuvenation of the drainage, and, altho this may be Pleistocene, it is possibly coincident with the better known disturbances of the West at the end of the Pliocene.

Glacial (Pleistocene) period.

The most prominent event of the glacial or Pleistocene period was the invasion of the United States by ice sheets from the north and the growth of local glaciers on many of the western mountains. Outside of the districts affected by the ice, the conditions and activities of the Tertiary period continued without radical change.

The ice sheets which invaded the northern states came from two distinct centers, the Labradorian and the Keewatin; the first spread over the northeastern states as far as southern Illinois, and the second covered the northern part of the Great Plains down to Kansas and Missouri. At times of greatest expansion the two coalesced along the Mississippi valley, but left a triangular area in Wisconsin untoucht. In the Atlantic highlands no local glaciers seem to have been generated, except on a few of the highest mountains during the retreat of the ice sheet. In the West, however, there were many glaciers. Long and broad lobes from the heavily ice-mantled mountains of western Canada spread southward into the United States along the meridional valleys. In addition large snow fields with diverging glacial tongues were distributed along the Pacific Mountains as far south as California, in the northern Rocky Mountains (including Yellowstone Park) and in the high mountains of Colorado. Smaller alpine glaciers were widely distributed thruout other western mountains and traces of them have been found even as far south as New Mexico, Arizona and southern California.

The effects of the glaciation differed according to local conditions. In the western mountains, valleys were excavated, peaks sharpened and divides reduced to arêtes, all combining to make the glaciated peaks more wild and rugged than before. The mountains of northeastern United States were completely buried by the ice sheet from the north and, in the process, were scoured, smoothed and rounded, but otherwise not greatly changed. In the inner lowlands of the upper Mississippi valley the changes due to glaciation are most prominent. There a hilly or nearly plane topography was overwhelmed with deposits of glacial drift, so that the present surface features are largely morainic. The pre-glacial valleys have been blotted out or locally obscured by deposits, of drift, and many streams have, since glaciation, taken new channels without reference to their older courses. Even such great rivers as the Mississippi flow in part thru post-glacial valleys.

There is clear evidence that the United States underwent more than one epoch of glaciation. In the western mountains two and locally three widely separated glacial epochs are distinct, but in the central interior as many as five and perhaps even six have been found recorded. The second or Kansan invasion extended farther south than any of the others but has been overridden at some points by later advances. There is lack of agreement as to the exact number of succeeding invasions, but in general it may be said that each fell somewhat short of the preceding one in the Mississippi valley, altho the last (Wisconsin) ice sheet overreacht all the others at some points east and west.

Altho it is possible that some of the distinct drift sheets represent merely re-advances of one ice sheet which had partially retreated, there is evidence to show that between some of the advances the ice sheets wholly disappeared and conditions not unlike those of the present time prevailed. Thus, beneath the Kansan drift sheet, the Aftonian interglacial beds preserve the remains of plants and mammals (*Elephas, Megalonyx, Equus, Camelus,* etc.), which suggest a temperate or warm climate. It is believed that the later interglacial stages were shorter and markt by less change in climate than the earlier. The latest invasion of the ice sheet was so recent that its deposits remain essentially unchanged by weathering and erosion. The same is true of the last glacial deposits in the western mountains.

The events of the slow retreat of the Wisconsin ice sheet were so recent that they are comparativly well known. The retreat appears to have been markt by many halts and probably brief re-advances. Where these halts were made, the recessional moraines were built, and, as the ends of the lobes retreated, the waters from the ice terraced the older deposits along the streams. During the retreat of the lobate edge of the ice-sheet, water accumulated in the depressions behind many of the moraines, and thus produced lakes. The Great Lakes of northeastern United States and Canada began in this way as isolated marginal lakes. As the ice withdrew they increast in size and one by one joined, until finally the five great lakes coalesced into one (Lake Algonquin). At first the individual lakes emptied southward by separate channels, but eventually they all discharged eastward down the Hudson River and finally down the St. Lawrence. A still larger lake called Lake Agassiz came into existence temporarily in North Dakota and Minnesota, stretching northward to Canada. It seems to have past out of existence when the Keewatin ice-sheet retreated to the vicinity of Hudson Bay and thus removed the ice wall which retained the lake.

In the western states flat deposits of lacustrin silts hemmed in on all sides by terraced mountain slopes show the existence there of large lakes during the glacial period. The best known and largest of these was Lake Bonneville[1], in Utah, of which the existing Great Salt Lake is a small remnant. Another, of very irregular shape, called Lake Lahontan[2], occupied parts of northwestern Nevada (see map, Fig. 42). Altho the existing remnants are now saline, some of these Pleistocene lakes discharged their surplus thru outlets and were doubtless fresh. There is evidence that Lake Bonneville attained its maximum size at the time when the glaciers from the adjoining Wasatch mountains extended farthest down their valleys. Corresponding to the two known epochs of glaciation in the mountains, there is proof of two epochs of lake expansion, separated, preceded and followed by periods of dessication. These facts are believed to show that the expansion of both lakes and glaciers was due solely to climatic causes, either a lowering of temperature, with consequent lessening of evaporation, or an increase of precipitation, or both. There is further evidence of such climatic changes in the behavior of many of the streams in western United States, for at some times in the Quaternary period they have excavated valleys and at other times filled these valleys with sediments. Such changes cannot apparently be ascribed with good reason to tectonic disturbances.

The effect of glaciation upon the plants and animals was important. The life zones must have shifted southward during the advances of the ice sheet and been permitted to extend northward again in the interglacial stages. Thus, remains of the musk-ox and other arctic species have been found as far south as central United States, and trees which now live along the Ohio River are known to have dwelt in Canada during one of the interglacial stages. During the glacial period many of the mammals characteristic of the Pliocene gradually disappeared, perhaps because of the stress of glacial

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[1] Gilbert, G. K., Lake Bonneville, U. S. Geol. Survey, Mon. I, 1890.

[2] Russell, I. C., Geological History of Lake Lahontan. U. S. Geol. Survey, Mon. XI, 1885.

migrations and counter migrations. Among those that past out are the South American edentates, the camels, horses, tapirs and saber-toothed cats. These losses, however, were compensated fór by the entrance from Europe of many new types which seem to have been better adapted to the cooler climate and general prevalence of forests. These immigrants include the bears, many types of deer and bovine ruminants. In the United States, however, there is as yet no satisfactory evidence that the human species had reacht this country before the Recent period.

The sparse distribution of marine sediments implies that the United States was but little more submerged in the glacial period than now, and only locally, at its extreme edges. The Quaternary limestone of Florida and the clastic deposits on the coast of California illustrate the different activities of those two regions.

That the volcanic activity which was so characteristic of the Tertiary period continued thru the Quaternary to the present is indicated by many widely scattered cinder cones in the basin and plateau states. Many of these cones are so fresh that they have scarcely been marred by erosion, and some of them are clearly post-glacial. Yellowstone Park seems to have been the site of further volcanic eruptions, and the geysers and hot springs which are now among its wonders are doubtless evidence that the volcanic phenomena have not yet wholly disappeared. Since there is clear evidence that the great volcanic cones of the Cascade mountains in Oregon and Washington have had some comparativly recent eruptions it is probable that they grew notably during the Quaternary period. In addition to volcanic disturbances there was evidently an intermittent continuation of the uplifts and general surface warping which appear to have begun at the close of the Pliocene. This is recorded in many facts. The older deposits of drift in the western mountains are trencht by canyons hundreds of meters deep, and along the Pacific coast Pleistocene deposits are found on terraces elevated hundreds of meters above the present sea level. Evidences of other changes of level of lesser magnitude are also abundant along the Atlantic coast.

Recent (Post-glacial) period.

Altho there is no good evidence that the glacial period is definitly completed and that we are now living in a new order of things geologically, so much is known about post-glacial events and changes that this epoch, while comparativly brief, deserves special mention. The Recent period is usually regarded as the time since the ice sheets made their final retreat. Inasmuch as the retreat itself was long and the glaciers have not yet disappeared from the higher mountains of the West and from the Arctic regions, no definit beginning can be assigned to this period. There is a general concensus of opinion in favor of the belief that the recession of the glaciers was due solely to a climatic change. There is further evidence that climatic cycles of much shorter duration have affected the United States and other continents within the recent period. Some of these are reflected in the historic expansions and contractions of saline lakes in western United States.

The mild diastrophic disturbances of the glacial period have apparently not ceased. Faulting has occurred long since glaciation along the front of the Wasatch mountains of Utah and even in historic times in several parts of California. The elevated beaches of California with deposits of modern shells show recent uplift. The old shore lines of the Great Lakes in eastern United States are no longer horizontal[1] but rise to the north and northeast, showing that they have been warpt since the ice sheets left the United States. Around the shores of Lakes Ontario and Champlain, clays containing marine shells and bones of whales have been found at elevations now 100 or more

[1] Leverett, F., Outline of the History of the Great Lakes. Mich. Acad. Sci., 12th Report, 1910, pp. 19—42.

meters above sea level, indicating considerable submergence followed by emergence, and all since the ice sheets disappeared. Even volcanic activity has not wholly ceast, altho apparently now dormant. Little cinder cones have grown up in the bottom of old Lake Bonneville since the Lake shrank to nearly its present size, and near Lassen Peak in California there seems to have been an explosiv eruption not more than two centuries ago. [1]

The fauna of glacial times lingered on in the United States after the ice sheets disappeared, as evidenced by the finding of many skeletons of the mammoth, mastodon and others in peat deposits resting upon the glacial drift. Probably some time after glaciation the human species made its appearance in the United States. That this advent occurred thousands of years ago is indicated by the great differences which now exist among the various tribes of American aborigines. There are several distinct stocks with unlike languages and even with important physical differences. If these dissimilarities are the products of evolution within the United States, one must assign to them a long period of time. If, however, they represent successiv migrations of different stocks from some other continent, the time may be reduced.

Attempts to express the time since glaciation in terms of years have been made frequently but with unsatisfactory results. Studies of the rate of recession of Niagara Falls and other cataracts seem to afford the most accurate basis and yet the estimates of these vary from 7000 to 60000 years. Some intermediate figure probably represents the duration of the Recent period.

IV. Orographic Elements.

Explanation.

An orographic element (as the phrase will be used in this chapter) is a region which is characterized by certain distinctiv geologic features, particularly by a certain type of structure, and a more or less unified geologic history. With these often go certain peculiarities of the rock formations and topography which serve to demark them from adjacent districts. As an example of such an orographic element we may take the Piedmont region of eastern United States,—where the rocks are generally schistose, intensely folded and very old. Furthermore, the element has been a land mass thruout much of its recorded history. The Coastal Plain may be taken as another example. There the rocks, chiefly of Mesozoic and Cenozoic age, lie essentially undisturbed and in part unconsolidated.

By comparing the maps, figures 1 and 4, the reader will see that the orographic elements recognized in this chapter tend to coincide with the physiographic provinces. This is but natural, since the distinctiv topography of such a province is an expression of its geologic structure as modified in the course of its own individual history.

In attempting to divide a large country such as the United States into orographic units it is necessary to make more or less arbitrary divisions; the different provinces often intergrade, so that to find sharp natural boundaries is often not merely difficult, —it is impossible. Also there are orographic elements of several degrees of magnitude. One could divide the entire country into only three elements or again into several hundred. The fifteen elements which have been selected in this instance are those which it is believed can be treated most advantageously within the allotted space of this chapter.

[1] Diller, J. S., Lassen Peak, Calif., folio. No. 15, U. S. Geol. Survey, 1895.

Appalachian Element.

General.

The Appalachian element lies near the eastern border of the United States, extending in a broad band from New York to Alabama. A thick prism of Paleozoic rocks has here been comprest into parallel folds which have a northeast-southwest trend. Northwestward the Appalachian tract grades into plateaus of horizontal Paleozoic rocks. On the southeast it is limited by the ancient metamorphic complex of the Piedmont element. Southwestward the folded beds disappear beneath the unconformable blanket of Cretaceous and Tertiary strata which form the coastal plain of the Gulf of Mexico.

Stratigraphy.

Schistose Complex. The ancient metamorphic rocks upon which the folded Paleozoic strata rest belong rather to the Piedmont region than to the Appalachian. There is, however, no sharp dividing line between the two elements in most localities.

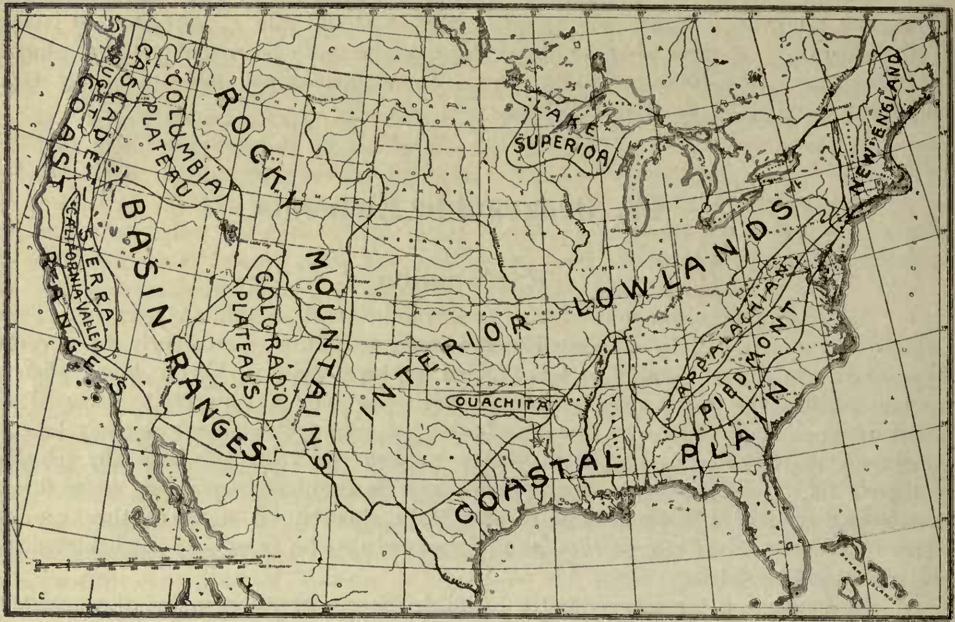


Fig. 4. Orographic elements of the United States.

Folded Paleozoic Strata. All divisions of the Paleozoic group are represented in this element and there are comparativly few gaps in the record. In the north the Hardiston, Chickies and correlated quartzites lie at the base of the sequence, and because of the presence of the *Olenellus* fauna, they have been referred to the Lower Cambrian series. In the extreme southern part of the province the sandstones and slates which contain the *Olenellus* fauna grade downward into a thick series of clastic sediments, formerly known as the Ocoee formation, which is 2000 to 3000 meters thick. Whether these pre-Olenellus beds are to be considered Cambrian or late Algonkian, it is certain that their relationship with the Paleozoic group is close. Thruout the province the sandy series grades up thru alternating shales, sandstones and limestones into a massiv limestone or dolomite of Cambro-Ordovician age. This limestone, known in the south as the Knox dolomite and in the north as the Shenandoah limestone,

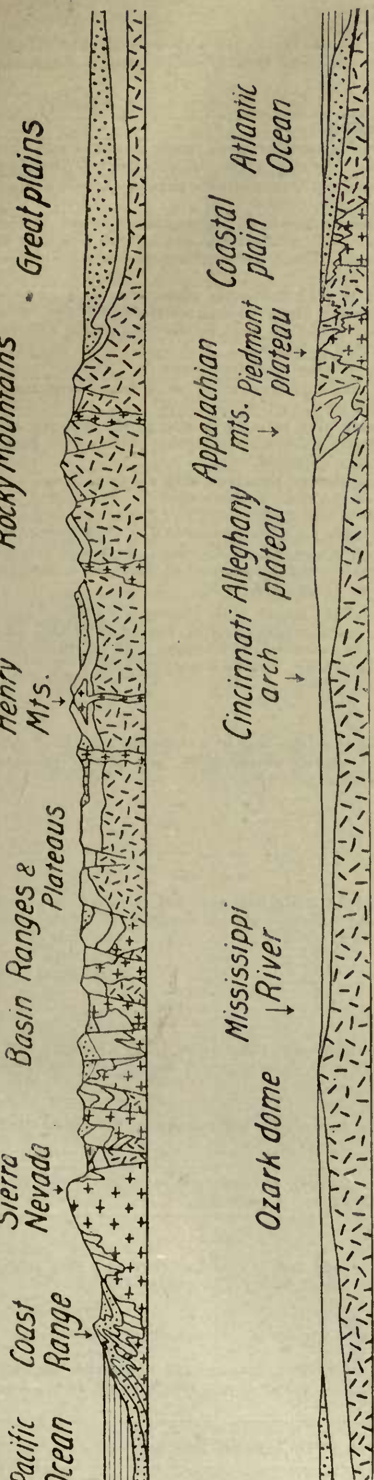


Fig. 5. Generalized profile across the United States near the 35th parallel of latitude. (Vertical scale 15 times the horizontal.)

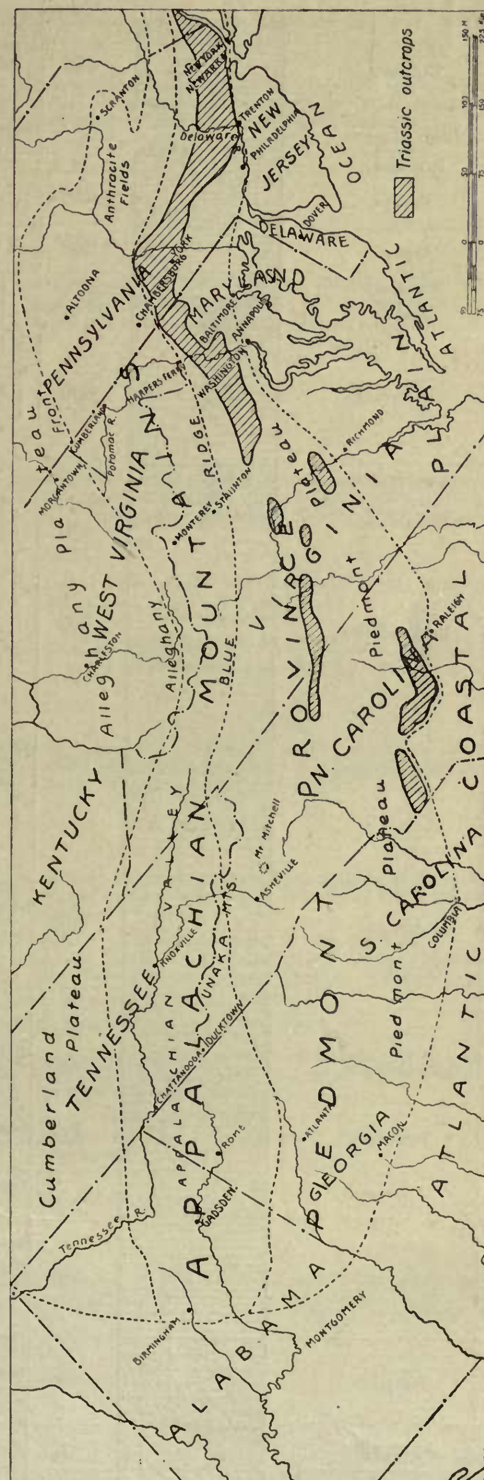
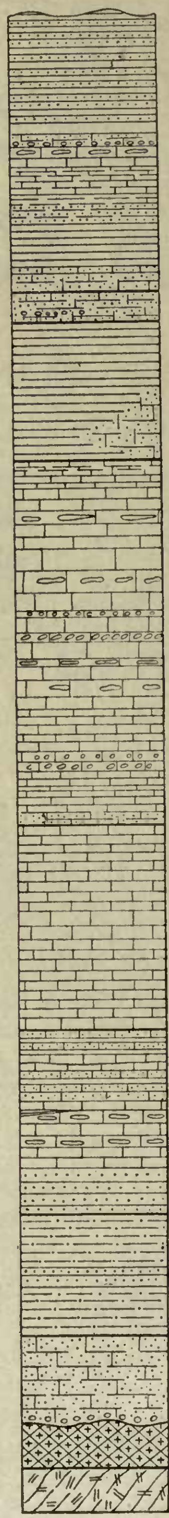


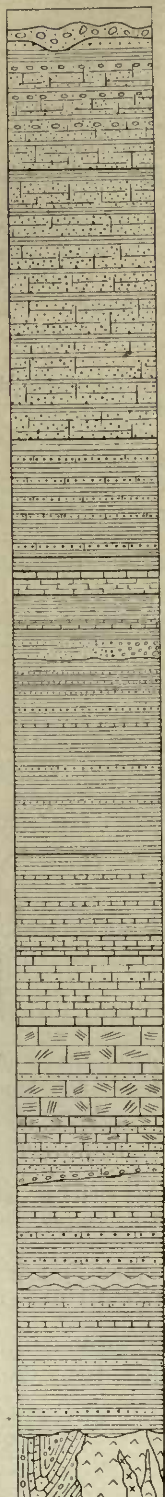
Fig. 6. Sketch map of the Appalachian and Piedmont elements.



Per.	Div.	Formation.	M.	Description.
Devonian.	Upper.	Chemung.	460	Alternating greenish gray to chocolate-colored sandy shale and thin micaceous sandstones. (*Spirifer disjunctus, S. mesistrialis,* etc.).
	L. M.	(Portage and Romney.)	?	Shales, not exposed.
		Oriskany.	55	White granular sandstone and cherty limestone with conglomerate at base. (*Spirifer arenosus, Rensselaeria ovoides*).
Silurian.		Helderberg.	90	Dark crystalline limestone with nodules of chert in upper portion. (*Spirifer macropleura*).
		Cayuga.	230	Finely laminar impure light gray limestone and calcareous shale.
		Clinton.	230	Red, green, and yellow sandy shale, with a bed of hard white sandstone. Tough red argillaceous sandstone near the base. (Ostracods). Soft red to pink fissile clay shale, with red sandstone in upper portion and flaggy white quartzite at the top. Thin soft calcareous sandstone beds below. (*Calymene Clintoni, Camarotoechia neglecta*).
		Tuscarora.	80	Massiv granular white sandstone.
Ordovician.		Juniata.	125–140	Soft red sandstone and shale with some hard sandstone and conglomerate.
		Martinsburg.	600	Chiefly dark gray to black shale, partly replaced eastward by soft greenish arkosic sandstone. (*Triarthrus beckii, Climacograptus spinifer*).
		Chambersburg.	30–230	Dark fossiliferous limestone with clayey partings. Interbedded shale at the top. Fossil zones: (*Tetradium cellulosum*). (*Echinosphaerites, Dinorthis pectinella*). (*Nidulites favus*). (*Christiania trentonensis*).
		Stones River.	200–320	Pure dove-colored limestone at top and bottom; gray fossiliferous limestone, with thin layer of chert, in middle. (*Maclurea magna, Tetradium,* etc.).
		Beekmantown.	700	Thick-bedded, rather pure limestone, with some magnesian beds; contains beds of oolite, fine conglomerate, coarse "edgewise" conglomerate, chert nodules, and quartz geodes. (*Bathyurus caudatus, Ophileta complanata*).
Cambrian.	Upper.	Conococheague.	500	Finely banded blue limestone with contorted laminae of slate. "Edgewise" conglomerate, chert, oolite, and porous sandstone, at the base. (*Dikelloccphalus hartii*).
	Middle.	Elbrook.	905	Gray to pale-blue shaly limestone and calcareous papery shale with some heavier limestone beds at the base and thick-bedded siliceous limestone in the middle.
		Waynesboro.	300	Slabby gray calcareous sandstone or sandy limestone and hard slaty purple shale, with white marble in middle. (*Obolus, Ptychoparia*).
	Lower.	Tomstown.	300	Limestone, in part cherty and magnesian, with beds of shale. (*Kutorgina, Olenellus*).
		Antietam.	150–250	Coarse white to gray quartzite and sandstone, with long Scolithus tubes. (*Olenellus, Hyolithes*).
		Harpers.	535	Dark-banded tough hackly schist or slate and thin sandstones with white quartzite in middle. (*Scolithus* tubes).
		Weverton.	380	Coarse gray feldspathic sandstone and white sandstone, with purplish arkose and hard purple quartz conglomerate at the base.
		Unconformity.		
Pre-Cambrian.		Aporhyolite.	?	Altered red to purple rhyolitic lava.
		Metabasalt.	?	Greenstone and chlorite schist derived from basalt flows.

SECTION IN THE APPALACHIAN MOUNTAINS IN SOUTHERN PENNSYLVANIA.[1]

[1] Adapted after G. W. Stose, U. S. Geol. Survey, 1910.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.		Late glacial. Unconformity.		0—90	Till; glacial stream deposits; lacustrine, and locally marine, clays.
Devonian.	Upper or Chautauquan.	Catskill.		520 +	Red to gray sandstone and conglomerate with red, blue and greenish shales. (Fossils rare; *Archaeopteris, Amnigenia catskillensis, Holoptychius americanus,* and *Dinichthys sp.*).
		Oneonta-Sherburne.		1075	Oneonta consists of gray sandstone alternating with beds of red, green, blue and dark gray shale; and the Sherburne of thin bluish sandstones and smooth shales. (Fossils very rare.)
	Middle or Erian.	Hamilton.		460	Blue argillaceous and arenaceous shales, with blue flaggy sandstones. *(Palaeoneilo constricta, Spirifer granulosus, Chonetes coronatus, Tropidoleptus carinatus, Nucula bellistriata,* etc.).
		Marcellus. Onondaga. Schoharie-Esopus.		115—175	Limestone and shale with thin sandstone. Highly fossiliferous. (For detailed descriptions see A next page).
	Lower.	Oriskany, etc. Unconformity (local).		35—156	
Silurian.	Upper.	Manlius, etc.		22—46	
	Lower (?)	Oneida-Shawangunk. Unconformity.		90—150	Conglomerate, grit and dark shale, alternating in thin bands (a varied arthropodous fauna, chiefly *Eurypterids*).
Ordovician.	Upper or Cincinnatian.	Lorraine or Frankfort.		760	Bluish to grayish argillaceous and arenaceous shales and sandstones. Fossils infrequent, but occasional graptolides, *Diplograptus foliaceus,* trilobites, brachiopods and cephalopods.
	Middle or Mohawkian.	Utica.		290—380	Black slaty calcareous shales with thin layers of limestone. *(Diplograptus quadrimucronatus, Triarthrus becki, Endoceras proteiforme).*
		Trenton.		60—120	Limestone. (For description see B next page).
		Amsterdam.		105	Dark gray limestone with sandstone at the base. *(Diplograptus dentatus, Orthis costalis, Harpes ottawensis, Illaenus arcturus,*etc.).
		Black River.		110	Dark limestone (*Maclurea magna,* etc.).
		Chazy		60	Dark limestone (*Camarotoechia plena,* etc.).
	Lower or Canadian.	Beekmantown. (Div. C, D, and E.)		365	Dolomite, limestone and calcareous sandstone of dark gray and brown colors. (In the upper part *Orthoceras, Raphistoma, Maclurea, Cyrtoceras, Harpes,* etc.).
Cambrian.	Upper or Saratogian.	Little Falls. Hoyt. Theresa. Potsdam. Unconformity.		183—285	Limestone, dolomite and sandstone. (For detailed description see C next page).
	Lower or Georgian.	Georgia.		4000 +	Red, purple and green roofing-slates, dark shales, interbedded sandstones and thin-bedded intercalated limestones. *(Olenellus asaphoides, Microdiscus pulchellus, Hyolithes americanus, Stenotheca rugosa).*
Pre-Cambrian.	Proterozoic (?).	Unconformity. Diabase dikes, and plutonic intrusivs. Grenville?			Anorthosite, intruded further by granite, gabbro and syenite. Gneiss, schist, ophicalcites, and marble interbedded; intensely folded and metamorphosed.

FORMATIONS OF EASTERN NEW YORK.[1]

[1] Compiled largely from publications of the New York State Geol. Survey, and revised by C. S. Prosser, 1911.

Detailed descriptions of thin formations in the eastern New York section.

A.

Marcellus. Black argillaceous shale with dark sandstone beds (*Liorhynchus limitare, Chonetes mucronatus, Goniatites discoideus, Agoniatites expansus*, etc.). 60

Onondaga. Massiv gray limestone with thin layers of chert (*Atrypa spinosa, Platyceras dumosum, Spirifer duodenaria*, etc.). 25

Schoharie-Esopus. Schoharie, dark impure limestone (*Meristella nasuta, Pentamerella arata, Conocardium cuneus*, etc.). Esopus, blackish arenaceous shales (*Spirophyton cauda-galli*). 30—90

Oriskany. Calcareous sandstone (locally quartzite) with conglomerate (*Hipparionyx proximus, Eatonia peculiaris, Spirifer arenosus, S. murchisoni, Rensselæria ovoides, Platyceras nodosum*). 1—18

Port Ewen (or Kingston). Impure shaly limestone and calcareous shale (*Dalmanella perclegans, Meristella laevis, Acidaspis tuberculatus*, etc.). 3—60

Becraft. Massiv light gray shell-limestone (*Sieberella pseudogaleata, Spirifer concinnus, Uncinulus nobilis, Aspidocrinus scutelliformis*, etc.). 4—12

New Scotland. Calcareous gray shale with thin beds of limestone. (*Stropheodonta becki, Spirifer macropleurus, S. cyclopterus, Eatonia medialis, Trematospira globosa, Phacops logani*, etc.) 18—48

Coeymans. Massiv dark gray shell-limestone, cherty. (*Sieberella galeata, Uncinulus mutabilis, Strophonella punctulifera, Lepadocrinus gebhardi*, etc.) 9—18

Manlius. Dark blue, compact thin-bedded limestone (*Holopea elongata, Spirifer vanuxemi, Stropheodonta varistriata, Leperditia alta, Tentaculites gyracanthus, ostracods*, etc.). 6—17

Roundout. Dark to light gray argillaceous magnesian limestone (fossils rare, ostracods, etc.). 6—16

Cobbleskill. Dark gray massiv limestone (*Favosites niagarensis? Acervularia? inequalis, Spirifer eriensis, Bellerophon auriculatus, Trochoceras turbinatum*). 2—6

Brayman. Soft argillaceous shale of olive, gray or blue color, containing pyrite nodules. (No fossils.) 8

B.

Trenton. Thin-bedded, dark blue, fine-grained limestone with black shale (*Prosopora lycoperdon, Diplograptus amplexicaulis, Trinucleus concentricus, Asaphus platycephalus, Calymene senaria, Rafinesquina alternata*, etc.). 30—60

Amsterdam. Dark bluish gray, massiv crystalline limestone. Highly fossiliferous. (*Prasopora* and Brachiopods.) 12

Black River. Bluish black to gray, massiv to thin-bedded, fine-grained limestone (*Columnaria halli, Stromatocerium rugosum, Zygospira recurvirostra*, etc.). 18

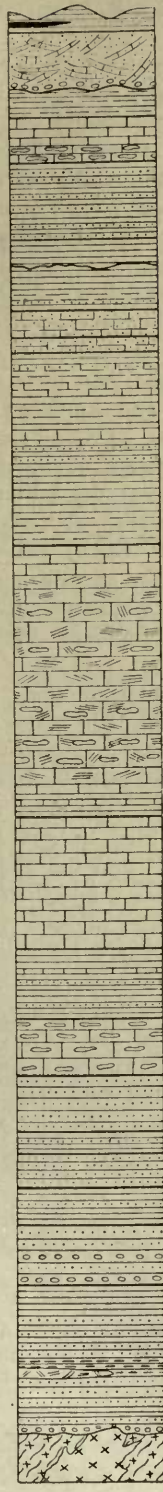
C.

Little Falls. Dolomite, light to dark gray crystalline. Fossils rare. 45

Hoyt. Blackish limestone alternating with beds of blue and light gray dolomite, containing many beds of black oolite. (*Cryptozoon proliferum*, trilobites, gastropods and *Lingulepis acuminata*.) 80—120

Theresa. Alternating beds of hard, vitreous sandstone, gray, calcareous sandstone, blue or gray crystalline dolomite and black, oolitic beds. (Trilobites and *Lingulepis acuminata*.) 40—60

Potsdam. Basal conglomerate and light colored vitreous sandstone, with occasional layers of calcareous sandstone in the upper portion. (In upper part *Dikelocephalus, Lingulepis pinniformis*, etc.) 18—60

Per.	Div.	Formation.	Strata.	M.	Description.
Carboniferous.	Upper.	Briceville.		90 +	Blue, gray, and black, argillaceous shale, with beds of sandstone and coal.
		Lee.		270	Massiv, white sandstone, locally cross-bedded, with layers of conglomerate near the bottom.
		Unconformity.			
	Lower.	Pennington.		120 +	Sandy and calcareous shales interbedded with thin layers of sandstone.
		Newman.		200—215	Blue and gray shaly limestone with fossils, above. Massiv blue limestone with cherty layers, below.
Devonian.		Grainger.		350—365	Bluish gray sandy shale and flaggy sandstone.
		Chattanooga.		120	Fine black carbonaceous shale.
		Unconformity.			
Silurian.		Rockwood.		215 +	Green, red, and yellow, sandy and calcareous shale, with beds of hematitic iron ore.
		Clinch.		90—150	Massiv white sandstone.
		Bays.		15—120	Massiv and shaly red sandstone.
Ordovician.		Sevier.		400—550	Calcareous sandstone, bluish, gray, and yellow calcareous shale and shaly limestone.
		Tellico.		1—60	Red and gray calcareous sandstone.
		Athens.		245—490	Black and bluishblack calcareous shale below, blue-gray banded slaty shale above (Graptolites).
		Chicamauga.		150	Massiv gray fossiliferous limestone.
		Knox.		900—1125	Magnesian limestone; light and dark bluish gray to white, with nodules and layers of chert and a few beds of calcareous sandstone.
Cambrian.	Upper.	Nolichucky.		15—185	Yellow, green, and brown calcareous shale with limestone beds.
	Middle.	Honaker.		550—670	Massiv dark blue and dark gray limestone. White and blue limestones.
		Watanga.		300—335	Purplish, red, green, and variegated shales, sandy shales, and thin sandstones, with calcareous shales and thin blue limestones interbedded.
	Lower.	Shady.		230—300	Gray, bluish gray, mottled gray, and white limestone, with nodules and masses of chert.
		Hesse.		215—300	Massiv white quartzite and sandstone.
		Murray.		90—120	Bluishgray to gray argillaceous and sandy shale and slate, with thin sandstone seams.
		Nebo.		60—275	Massiv white quartzite and sandstone, coarse and fine, with layers of sandy shale, slate, and reddish sandstone.
		Nichols.		120—215	Bluish gray to gray argillaceous and sandy shale and slate, with thin sandstone layers.
		Cochran.		60—490	Massiv quartzite, sandstone, and conglomerate, white or gray, with seams of dark slate.
		Hiwassee.		90—460	Bluish gray to black and banded slates with a little fine mica-schist. Includes layers of sandstone and conglomerate.
		Snowbird.		250—600	Gray and white feldspathic quartzite, with dark slate beds and a lentil of amygdaloid lava. Fine quartz conglomerate and arkose at base.
		Unconformity.			
Archean.				(?)	Granite and granite-gneiss.

FORMATIONS OF THE SOUTHERN APPALACHIAN MOUNTAINS IN EASTERN TENNESSEE AND VICINITY.[1]

[1] From reports by A. Keith, N. H. Darton, and others, U. S. Geol. Survey.

has an average thickness of more than 1000 meters. It is generally magnesian and poor in fossils.

The limestone is overlain, unconformably according to some investigators, by shale and limestone of middle and late Ordovician age, and these in turn are followed by coarse sandstones or quartzites (Oneida, Medina and others) with local conglomerates. This clastic series is now regarded as marking the transition from the Ordovician to Silurian system. On the upper or Silurian side, the sandy series grades into the Rockwood formation, which consists of shale with local bodies of limestone. Important deposits of iron ore, in the form of bedded layers, are interleaved with the other sediments of this formation thruout the Appalachian region.

The Devonian beds, which rest upon the Rockwood, or upon a still younger limestone of Siluro-Devonian age, generally appear to be conformable upon their base, but in many localities there is evidence of an obscure unconformity without discordance. Where present, the lower Devonian beds are limestone, and these in turn are followed by dark shales. In the southern portion the shale and limestone are very thin and seem to represent only a part of the Devonian period. From Pennsylvania to Virginia, however, the full Devonian system is present, comprising a succession of dark sandy shales and sandstones with local beds of limestone near the bottom,—altogether nearly 2000 meters thick. These sandy beds become reddish at higher horizons and pass up conformably into the Mississippian sandstones (Pocono) followed by the Mauch Chunk shale above. The latter are probably nonmarine deposits, nearly devoid of fossils and suggestiv of a subarid climate. When traced southwestward to Tennessee, the Pocono and Mauch Chunk pass into much thinner formations chiefly of dolomitic limestone and chert, overlain by shales.

The Pennsylvanian system begins with the Pottsville series of coarse sandstones and conglomerates, which are thickest in Pennsylvania. In some localities the Pottsville rests upon the eroded surface of the Mississippian, but in other places the two systems seem to intergradate thru continuous terrestrial sediments. The Pottsville sandstones pass upward into the alternating series of sandstone, shale, limestone and coal, familiarly known as the Coal Measures. Three distinct formations constitute the Coal Measures,—the Alleghany, the Conemaugh, and the Monongahela. Of these the first and last contain many workable beds of coal, while the second is often known as the "lower barren measures." Paleontological zones in these formations are based chiefly on plant remains. In the lower division there are limestones containing marine upper Carboniferous fossils. In the Conemaugh remains of reptils have recently been found, and these, together with the fossil insects, suggest Permian rather than Pennsylvanian faunas. The testimony of the plants, on the other hand, favors Upper Carboniferous age. Inasmuch as the Pennsylvanian formations are the youngest beds exposed in the Appalachian geosyncline, their original thickness is not known. The portion which remains is thickest in the northeast and generally much thinner in the southwest, but it is evident that, in the latter place, the thickness has been greatly reduced by erosion.

There is good reason to believe that Permian rocks once formed a part of the Appalachian succession but, if so, they have been entirely worn away. They still exist in the Alleghany plateau not far northwestward.

Volcanic Rocks. There is nothing more surprising about the Appalachian mountains than the almost complete absence of igneous rocks. There are no large intrusions or masses of surface volcanics,—nothing but a few small dikes, chiefly of basalt and granite porphyry, scattered thru the central portion of the province. They are post-Carboniferous, — perhaps Triassic.

Younger Undeformed Strata. In the southern and central part of the Appalachian element there are no extensiv deposits of later age than the folded

Paleozoic beds. Here and there small patches of terrestrial sand and gravel, probably of Tertiary and Quaternary age, rest upon the older rocks. In Pennsylvania and New York the extreme northeastern end of the mountains is veneered with Quaternary glacial drift.

Structure.

Appalachian structure has become classic thru the works of ROGERS, WILLIS, HAYES and many others. The existing mountains have been carved from a series of long parallel folds, many of which are overturned toward the northwest. The intensity of folding decreases from southeast to northwest. The folds, therefore, are most closely apprest in the eastern and especially the southeastern part of the province. There, also, the folds are associated with many parallel overthrusts, some of which have themselves been much folded, as has been shown by HAYES[1] and KEITH.[2] The compression to which these rocks have been subjected is estimated to have shortened the original surface in this region about 65 to 80 kilometers.

Unlike many great folded tracts the Appalachian element does not include large igneous intrusions.

Geologic History.

The history of the Appalachian province proper, begins with the deposition of the great series of Paleozoic sediments. This commenced in or before the Cambrian and was brought to a close probably in the Permian period. Thruout that great lapse of time the region was low and was for long periods beneath the sea. The times of submergence were interrupted by occasional emergences during which the surface of the older sediments was subject to weathering and even to activ erosion. One of the most important of these emergences occurred near the close of the Ordovician period, apparently at the time the Taconic revolution was taking place in the New England and Piedmont provinces. There were other important emergences early in the Ordovician, late in the Silurian period and between the Mississippian and Pennsylvanian periods. Altho deformation accompanied some of these movements in other regions, the Appalachian element seems not to have been affected by anything more than a change of level.

At other times the sea bottom was built above sea level by the deposition of sediment, — perhaps chiefly by coastal streams. This is particularly true of the Devono-Carboniferous age. The great thickness of the Appalachian sediments is ascribed partly to the presence on the southeast of an old land mass (Appalachia) now represented in part by the Piedmont element.

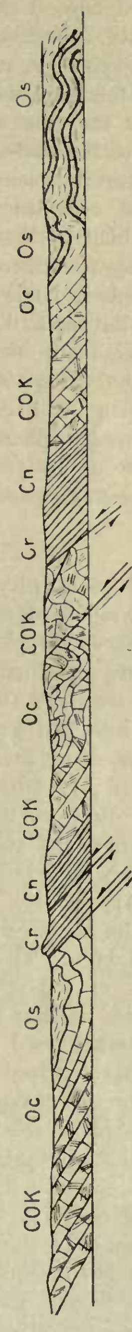


Fig. 7. Profile of folded Paleozoic beds in southern Appalachian Mts., eastern Tennessee. Direction: (After A. KEITH, U. S. Geol. Surv.) — Cr, Rome shale, Cambrian; Cn, Nolichucky shale, Cambrian; COK, Knox dolomite; Oc, Chickamauga limestone; Os, Sevier shale ordovician. Length of profile 20 kilometers.

[1] HAYES, C. W., Rome, Ga.-Ala., folio (No. 78). Geol. Atlas U. S., U. S. Geol. Survey, 1902.

[2] KEITH, A., Roan Mountain, Tenn.-N. C., folio (No. 151) 1907; and Cranberry, N. C., folio (No. 90) 1903. Geol. Atlas U. S., U. S. Geol. Survey; and other folios.

Toward the close of the Paleozoic era the sea appears to have been pusht westward beyond the border of the Appalachian mountains and the region was the site of fluviatil deposition. The vast series of swamps represented by the coal seams of the Pennsylvanian strata must have extended from one end of the Appalachian province to the other and westward far beyond its borders.

At the close of this time there occurred the most striking event in the later history of the eastern region, namely, the compression and folding of the Paleozoic rocks near the close of the Permian period. A tangential force, apparently from the southeast, crowded the ancient rocks of Appalachia against the great Paleozoic geosyncline, which by that time was deeply filled with sediments. There is little doubt but that these movements produced not only the observed folds and overthrusts but at the same time a chain of high mountain ranges far more rugged than their descendants,—the modern Appalachians. During the succeeding Mesozoic era the atmospheric forces gradually demolished the ranges and removed from the western flank of the mountains every vestige of those fringing conglomeratic beds which are always laid down upon the borders of high mountain ranges.

In subsequent time, it appears that there have been no great changes, either in structure or in geography. The development of topography in the region is sketcht in the ensuing pages.

Physiography.

Topography. The topography of the Appalachian province is characterized by many parallel ridges separated by as many parallel valleys. The majority of the ridges mark the outcropping edges of inclined hard layers of rock on the flanks of folds; others are anticlinal or synclinal. The valleys have been excavated along the outcrops of less resistant strata between. In a large way the Appalachian element may be divided into two topographic regions. On the east stands a chain of mountains rising 1000 meters or more above sea-level. It is called the Blue Ridge in the north but is designated by various local names in the southwest where its summits are considerably higher. Between these ridges and the bold east-facing escarpment of the Alleghany and Cumberland plateaus (part of the Interior province) stretches a wide hilly lowland, the surface of which is more or less broken by low level-topt mountain ranges. This is the Appalachian valley.

The drainage in the Appalachian element is well adjusted to the folded hard and soft beds. Thus most of the smaller streams have worn out valleys along the outcrops of soft strata, while the main rivers here and there cut directly across the structures, passing the hard layers in picturesque gorges known as "water gaps".

Origin and History of the Topography. The physiographic history of the region has received the attention of many geologists. The prevalent flat tops of the mountain ridges represent an ancient plain of denudation or peneplain. It is clear that this peneplain was carved out early in the Mesozoic era, altho it was doubtless not perfected until Cretaceous times. Not all of the region was reduced to base-level, for there is evidence that the higher mountain ranges of the southern Appalachians maintained, even to the last, a mountainous topography. Of the results of this early cycle of erosion Hayes[1] writes: "At the close of the first cycle, then, the whole province, except a few residual areas, was reduced to an almost featureless plain, over which the streams flowed with sluggish currents in meandering courses. Their transporting power was greatly diminished, so that the land was being degraded almost wholly by solution and the surface was covered by a heavy mantle of residual material,

[1] Hayes, C. W. and Campbell, M. R., Geomorphology of the southern Appalachians. National Geographic Magazine, vol. VI, 1894, pp. 104—105.

resulting from a long period of subaerial rock decay. The divides were low, slopes gentle, and the drainage systems delicately adjusted among themselves."

This relativly flat surface, called the Schooley or Kittatiny peneplain, remained undisturbed until some time within the Tertiary period, when a slight differential movement or warping raised the surface of the Appalachian element and much of North America adjacent sufficiently to quicken the activities of the streams, so that they sank their valleys deep into the Kittatiny plain. During the slow progress of this upwarp, the master streams such as the Potomac River, generally maintained their original courses and sawed their channels across hard and soft strata alike. By an interesting series of readjustments and stream captures, other rivers, such as the Tennessee, largely changed their courses. All erosiv activities so concentrated their action upon the softer strata that the outcrops of the harder beds now stand out in relief as ridges which still retain the flatness of the old peneplain. These processes seem to have occupied a considerable part of the Tertiary period, and altho that was not sufficiently long to permit the base-leveling of the hard ridge-making layers, it did allow the excavation of wide flat-bottomed valleys.

Afterward, during the Tertiary and Quaternary periods, successiv changes of level, partly depressional but chiefly elevatory, and doubtless also changes of climate, influenced the rate of erosion and thus induced the cutting of still deeper terraced valleys, of which the more recent are still young and ungraded.

Seismicity.

The Appalachian element is one of the most stable in the United States. Within historic times no earthquakes of importance and indeed very few shocks perceptible to the human senses have originated there.

Ouachita Element.

General.

The Ouachita mountain system includes the folded structures and resulting mountains of east-west trend in central Arkansas and southern Oklahoma. These are entirely isolated by superficial deposits, but they resemble the Appalachian system in so many respects that it has been suggested that the two systems are actually joined beneath the Cretaceous and Tertiary beds of the Mississippi embayment. In Arkansas the rocks are chiefly of Paleozoic age and were folded near the close of that era. Farther west pre-Cambrian rocks are exposed in the cores of broad anticlinal folds. In the extreme west (Wichita Range) irregular bodies of ancient granite and porphyry rise island-like from the level Permian sediments.

Stratigraphy.

Folded Rocks. The pre-Cambrian rocks reach the surface only in Oklahoma near the western end of the Ouachita system. Granite predominates. Upon the eroded surface of the granite rests a thin sandstone with middle Cambrian fossils. This in turn is followed by a great thickness of Cambro-Ordovician limestone (Arbuckle formation), which seems to be partly equivalent to the similar Knox dolomite of the southern Appalachian mountains. The limestone is followed, generally conformably, by a thin succession of limestone and shale within which there are obscure unconformities. This thin succession represents the Silurian and Devonian period. Again conformably, there follows a very thick series of shale and sandstone with a few beds of limestone; of this the lower part is Mississippian while the upper is Pennsylvanian. In Arkansas and eastern Oklahoma there are a few coal seams in the upper portion. Permian rocks appear only in the extreme west and their relations to the Pennsylvanian are

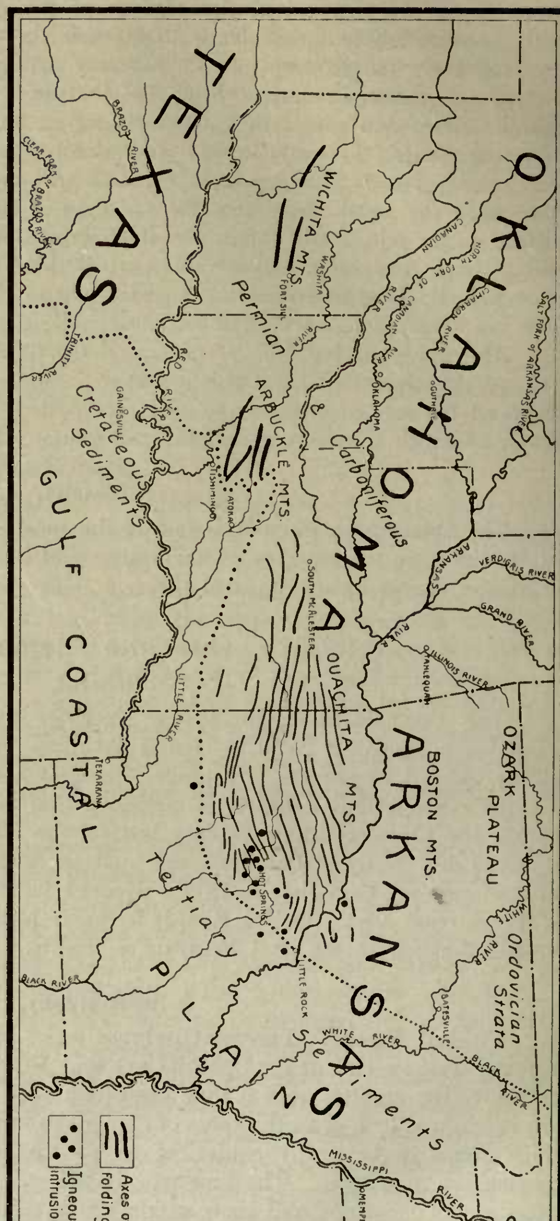


Fig. 8. Sketch map of the Ouachita element and vicinity.

Fig. 9. Profile across the Ouachita Mountains of western Arkansas, showing folded Paleozoic rocks (Ark. Geol. Survey). 1 Ordovician shale, etc. 2 Novaculite. 3 Lower Carboniferous sandstone. 4 L. Carb. shale.

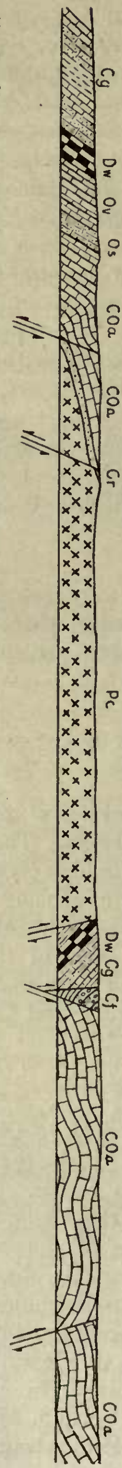


Fig. 10. Profile of the Arbuckle Mountains in southern Oklahoma. (After J. A. Taff, U. S. Geol. Surv.) — PC, pre-Cambrian granite; Cr, Reagan sandstone, middle Cambrian: COa, Arbuckle limestone, Cambro-Ordovician; Os, Simpson formation, Ordovician; Ov, Viola limestone, Ordovician; Dw, Woodford chert, Devonian with Silurian limestone at the base; Cg, Glen formation, Mississippian and Pennsylvanian shale, sandstone and limestone; Cf, Franks conglomerate, Pennsylvanian (?). Length of profile about 30 km.

still in controversy. According to Taff[1], the latest Pennsylvanian rocks in the Arbuckle mountains rest unconformably upon all of the older formations in succession.

Undeformed Sediments. The truncated edges of all of the older formations are covered irrespectivly by horizontal sands and shales of Comanchean (Lower Cretaceous) age. These border the mountain system on the south and east. In the west, red gypsiferous beds chiefly of Permian age overlap the folded rocks in the same way. Upper Cretaceous beds are lacking and the early Tertiary strata touch the district only on its eastern border. Unconsolidated late Tertiary and Quaternary sand and loam have a wide distribution around the edges of the mountain groups.

The folded rocks in Arkansas are cut by a few dikes and pipelike intrusions of basic igneous rocks belonging chiefly to the nephelinite group and grading off into peridotites. These intrusions have invaded also the flat-lying Cretaceous beds and are believed to be of early Tertiary age. Attention has recently been attracted to one of the peridotite pipes by the discovery that it contains diamonds. The relations are said to resemble the well known diamantiferous deposits of South Africa.

Structure.

The strata in the eastern mountains of the Ouachita element are involved in close folds with a general east and west trend. Griswold[2] depicts them as constituting an abnormal anticlinorium. In so far as they have been studied, the folds seem to be accompanied by fewer overthrust faults than in the southern Appalachians. In parts of Oklahoma, normal faults of later age than the folding have cut the already deformed strata into many irregular blocks, so that the folds appear less prominently in the general structure. It is estimated that the compression has resulted in a reduction of 40 per cent in the original breadth of the district, and the driving force is believed to have come from the south.

It appears that a zone of faults with large aggregate displacement stretches from Atoka, Oklahoma, along the south side of the folded region to the vicinity of Little Rock, Arkansas.

The formations younger than Paleozoic lie almost horizontal and quite undisturbed. They have a very gentle dip toward the south, an inclination which may be that of original deposition.

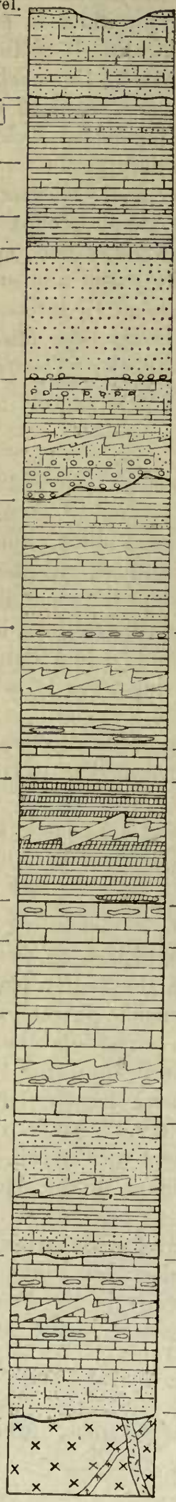
Geologic History.

The oldest rocks of the district are granites which were evidently intruded into still older rocks of which nothing is known. Upon the nearly base-levelled surface of this ancient complex were then deposited in conformable succession the thin Cambrian sandstone and the great series of limestones which constitute the Arbuckle formation. With minor interruptions marine deposition continued until the Carboniferous period, during which sedimentation seems to have been more largely terrestrial. Either late in the Pennsylvanian period or soon afterward, the Paleozoic rocks were comprest from the south and ridged into folds with a east-west trend. It is still uncertain whether this disturbance was coeval with the folding of the Appalachian Mountains or earlier.

After the folding the resulting mountains were largely worn down, and in the course of this erosion beds of conglomerate were deposited along the borders of the Oklahoma ranges. At a still later time, probably early in the Mesozoic era, the folds were broken by normal faults, now especially prominent in the Arbuckle and Wichita

[1] Taff, J. A., Geology of the Arbuckle and Wichita Mts., in Okla., U. S. Geol. Survey, Prof. Paper 31, 1904, p. 34.

[2] Griswold, L. S., Whetstones and Novaculites of Arkansas. Ark. Geol. Survey, Rep. for 1890, III, (Map in pocket).



Per.	Div.	Formation.	M.	Description.
Quaternary.		River sand.		Fine river sand and silt.
		Terrace sand and gravel.	0—15	Gravel and sand.
Cretaceous.	Gulf series.	Unconformity.		
		Silo.	60 +	Brown friable sandstone, shale, and shaly sandstone.
Comanchean.		Obscure unconformity.		
		Bennington.	3—5	Blue limestone composed chiefly of shells. *(Exogyra arietina).*
		Bokchito.	43	Red and blue shale with ferruginous limestone and lentils of friable sandstone. *(Ostrea).*
		Caddo.	46	Yellow and white limestone and marl.
		Kiamichi.	15	Blue friable shale; thin limest. compos. chiefly of shells in upper portion.
		Goodland.	8	Massiv white limestone.
		Trinity.	60—120	Fine yellow sand with conglomerate beds locally at the base (fossil wood).
		Angular unconformity.		
Pennsylvanian.		Franks.	90—150	Limestone and chert conglomerate, gritty sandstone, limestone, and shale. Probably represents the upper portion of the Glenn formation and lies unconformably on all the older Paleozoic formations. Possibly Permian.
		Angular unconformity.		
		Glenn.	305—915	Blue shale with thin brown sandstone and occasional thin limestone. (Lower part Mississipian [?]).
Mississippian.		Caney.[1]	460	Blue shale with thin sandy lentils and small ironstone concretions. Black fissil shale with dark-blue fossiliferous limestone concretions. (*Productus hirsutiformis, Leiorhynchus, Gastrioceras,* etc.).
		Sycamore.	0—50	Bluish to yellow limestone.
Devonian.		Woodford.	185	Thin-bedded chert and fissile black shale. Local blue flint lentils at the base.
Silurian.		Hunton.	0—60	White and yellowish limest. with flint and chert concret. in upper part. (*Triplecia Ortoni, Calymene niagarensis, Gypidula galeata,* etc.).
Ordovician.		Sylvan.	15—90	Blue clay shale.
		Viola.	230	White and bluish limestone with flint concretions in the middle. (*Trinucleus concentricus, Clymacograptus typicalis,* etc.).
		Simpson.	490	Bituminous sandstone, calcareous sandstone, and shale. Thin fossiliferous limestone and shale. (*Orthis tricenaria, Dalmanella pervela,* etc.). Bituminous sandstone, calcareous sandstone, and shale. Fossiliferous limestone and shale. (*Orthis costata, O. pogonipensis, Bathyrurus sp.,* etc.). Sandstone and shaly beds.
		Obscure unconformity.		
		Arbuckle.	1225—1830	Massiv and thin-bedded white and light-blue limestone with cherty concretions. (*Maclurea, Hormoloma, Orthoceras,* etc.). Dull blue massiv and thin-bedded limestone, sandy at the base. (*Dikellocephalus, Illaenurus,* etc.).
Cambrian.		Reagan.	15—46	Coarse darkbrown sandstone at base; calcareous sandstone and shale at top. (*Obolus, Acrotreta, Agraulos,* etc.).
		Angular unconformity.		
Pre-Cambrian.		Tishomingo.		Coarse red granite and monzonite, with diabase, granite-porphyry, and aplite dikes.

GENERALIZED SECTION FOR THE TISHOMINGO REGION IN SOUTHERN OKLAHOMA.[2]

[1] Probably early Pennsylvanian. — [2] Modified after J. A. Taff, U. S. Geol. Survey, 1903.

mountain groups. After all of these sediments had been nearly base-levelled by erosion, the non-marine Trinity sands (Comanchean or Lower Cretaceous) were strewn widely over the monotonous surface. By the gradual invasion of the sea, a considerable thickness of marine shale, chalk and sand was laid down in alternating layers. If the upper Cretaceous strata ever extended so far north and east, they have all been removed by erosion. About the end of the Cretaceous period, the dikes and other intrusions in central Arkansas were formed, but there is no evidence to indicate that there were surface eruptions. The subsequent history of the region involves chiefly the varying erosion of the surface, under the influence of mild changes of level, and the deposition of thin layers of terrestrial sand and clay along the rivers.

Physiography.

The topography of the folded ranges of Arkansas is much like that of the central Appalachians. There is a succession of parallel ridges, the tops of which are nearly flat and attain a common level. Over wide areas in Oklahoma the sedimentary beds have been worn flush with the modern land surface, and the existing mountains are low rounded masses which owe their elevation to resistant massiv granitic rocks of pre-Cambrian age.

There is evidence that the region was nearly base-levelled before the Comanchean period,—as in the Appalachian district already described. According to J. A. Taff[1], the Jurassic peneplain with its cover of Cretaceous sediments, was warpt and slightly tilted southward early in the Tertiary period. In consequence of this, the Mesozoic sediments were stript off in the north, and a new peneplain, embossed with low residual hills, was carved in adjustment to the new relations. Part of the plain now truncates the Cretaceous beds south of the mountains, while the rest of it is excavated beneath the Jurassic plain within and north of the mountains, and has largely obliterated that feature. This would seem to correspond to the familiar Tertiary base-level of the Appalachian mountains. In the Quaternary period other slight changes of grade, chiefly elevatory, have caused the excavation of broad flat-bottomed valleys beneath the Tertiary peneplain, leaving the latter in the form of terraces and flat-topt hills.

Seismicity.

The Ouachita region resembles the Appalachian province seismically as well as otherwise. No important earthquakes have ever been recorded from the district and even perceptible tremors are rare.

New England Element.

General.

The political division of New England, with the addition of its natural extension in Canada and the eastern border of New York, corresponds rather closely with the geologic province which may be regarded as in fact a continuation of the Piedmont element farther southwest. The prevailing rocks are highly folded and in many places metamorphosed past recognition. The formations were originally of both sedimentary and igneous origin, and comprise rocks ranging in age from pre-Cambrian to Carboniferous. Small patches of unaltered and but moderately disturbed Triassic rocks are scattered thru the southern part of the district. The late Quaternary ice sheet spread over the entire province a mantle of drift thru which many isolated rocky hills protrude.

[1] Taff, J. A., Tishomingo, I. T., folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1901.

Stratigraphy.

Metamorphic Series. The prevailing body of metamorphic rocks is not only highly altered but has an intricate structure induced by repeated periods of folding and faulting. For these reasons the geologic structure and succession are still but imperfectly understood, altho they have been long and carefully studied by several generations of able geologists from Silliman and the elder Hitchcock to Dale and Emerson. Only here and there have the rocks yielded fossils by which their age could be recognized.

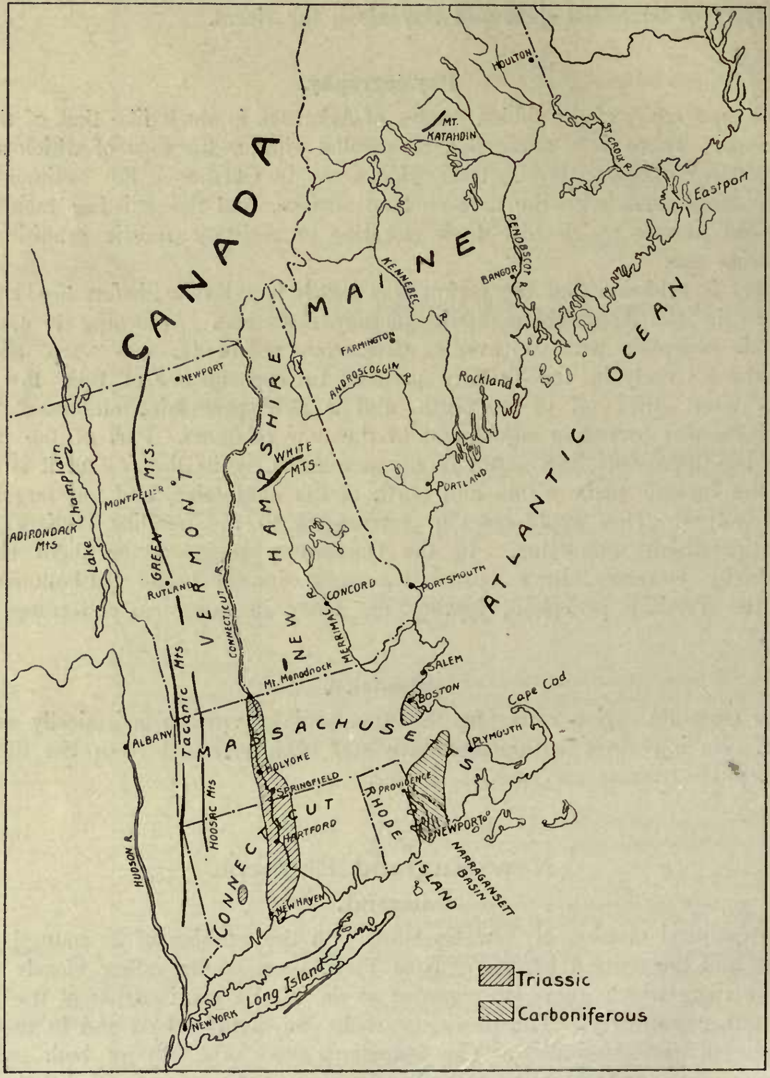


Fig. 11. Sketch map of the New England element.

In western Connecticut, Massachusetts and Vermont, highly folded sedimentary rocks now in a semi-metamorphic condition, form the Taconic, Green and adjacent mountain ranges. The rocks consist of crystalline limestone, quartzite, and slate, with various gneisses and schists. Some of them may well be of pre-Cambrian age, but

the greater part of the succession is known to be Cambrian and Ordovician, for distinctiv fossils have been found in favored places where the rocks are not too much metamorphosed.

Farther east, in central Massachusetts[1], highly schistose beds, which are thought to be the equivalent of these, are overlain unconformably by Silurian schists, argillites and crystalline limestone, and these in turn by a complex series of Devonian strata. All of these Paleozoic beds are partly metamorphosed and are cut by intrusions of granite, quartz-diorite and other igneous rocks, the age of which is said to be Carboniferous, but may as well be either late Devonian or Permian. Many rare and interesting minerals have been found in the pegmatite dikes associated with these intrusions.

In eastern New England the geologic relations are still more complex and, because of the generally thicker blanket of glacial drift, the facts are well known in but few localities. In eastern Massachusetts lower *(Olenellus)* and middle Cambrian fossils *(Paradoxides harlani, Agraulos quadrangularis)* have been found in folded slates, the relations of which are imperfectly known. The rocks are intruded by granite, gabbro and certain rarer igneous rocks, such as nepheline syenite and essexite.

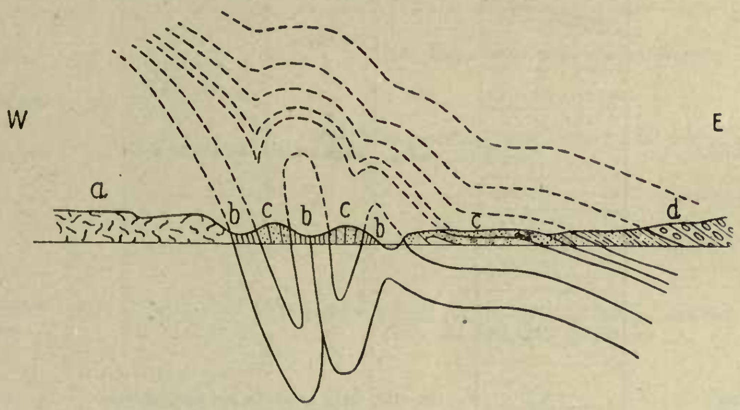


Fig. 12. Diagram showing hypothetical structure of Carboniferous beds near Providence, R. I. a, older igneous and schistose rocks; b, slate; c, sandstone and grit; d, conglomerate. (After N. S. Shaler, U. S. Geol. Survey.)

In Rhode Island[2] a deep and complexly folded synclinorium has preserved a thick sequence of Carboniferous beds. The prevailing rocks are coarse conglomerate, arkose and slate, but they contain a few beds of graphitic coal, with which are associated unquestionable Pennsylvanian plant remains. Altho the Carboniferous formations rest in evident unconformity upon the older schistose Paleozoic rocks, with granitic intrusivs, they are themselves intruded by batholiths and dikes of granite and pegmatite, and in some places have been notably metamorphosed.

On the coast of Maine[3] limestones, thought to be equivalent to the Cambro-Ordovician limestones of the Appalachian district, are separated by an unconformity from fossiliferous Silurian slates, which are in turn followed by volcanic tuffs thought to

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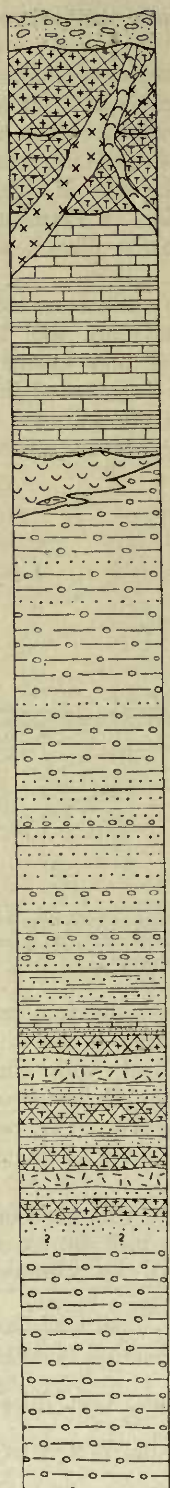
[1] Emerson, B. K., Geology of Old Hampshire County, U. S. Geol. Survey, Mon. 29, 1898.

[2] Shaler, N. S., Woodworth, J. B., and Foerste, A. F., Geol. of Narragansett Basin, U. S. Geol. Survey, Mon. 33, 1899.

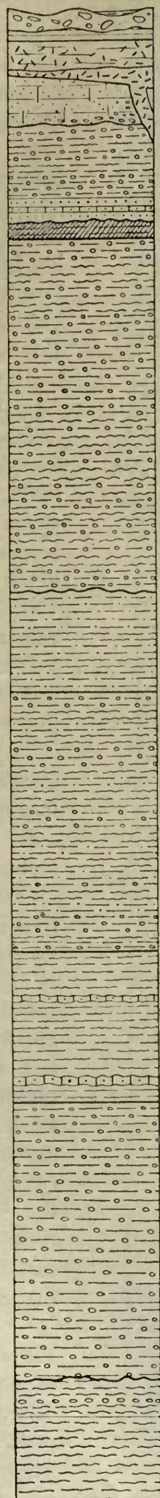
[3] Smith, G. O., Penobscot Bay, Me., folio (No. 149), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

Bastin, E. S., Rockland, Me., folio (No. 158). Geol. Atlas U. S., U. S. Geol. Survey, 1908.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.	Recent.			?	Marine clay and sand.
	Pleistocene.			?	Glacial till, with associated sand and gravel.
Devonian (?).		— Unconformity. — Vinalhaven.		?	Biotite granite, diorito, diabase and gabbro, intrusiv into the older formations.
				?	Rhyolitic flows, tuff and breccia.
Silurian (?).		Thorofare.			Andesitic flows, tuff, breccia and amygdaloid.
Silurian.	Middle?	Ames Knob.		180	Gray limestone interbedded with red and gray shale. (*Favosites niagarensis, Calymene niagarensis, Illaenus ioxus, Pentamerus, Spirifer radiatus*, etc.)
Ordovician (?).		— Unconformity. —			Serpentine intrusiv in Cambrian rocks.
Cambrian (?).		Penobscot.		?	Dark schists and quartz slate.
		Battie.		120—150	Gray quartzite and conglomerate.
		Islesboro.		?	Dark quartz slate and impure quartzite with a few beds of limestone, associated with thick masses of diabase, rhyolite, andesite, trachyte, dacite, and other volcanics, in the form of flows, tuff and breccia.
Pre-Cambrian (?).		Ellsworth.		?	Gray and green mica- and chlorite-schists.

SECTION NEAR PENOBSCOT BAY, MAINE.[1]

[1] Adapted after G. O. Smith, E. S. Bastin, and C. W. Brown, U. S. Geol. Survey, 1907.



Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.					Glacial drift, lake beds, etc.
		Unconformity.			
Triassic.		Chicopee.		60	Sandy carbonaceous shale.
		Granby.		175	Agglomerate of diabase, interstratified with sandstones.
		Blackrock.			Volcanic cones and dikes of diabase.
		Longmeadow.		300+	Feldspathic, ferruginous sandstone (conglomeratic and 1400 meters thick on west side of Triassic trough).
		Unconformity.			
Devonian.		Bernardston.		595	Dark mica-schist, with several beds of amphibolite, over quartzite (200 meters) containing a bed of highly crystalline limestone (6? meters). Unrecognizable *Spirifer*, *Microdon*, *Paleoneilo*, and *Camarotoechia* (? upper Devonian).
		Unconformity.			
Silurian.		Leyden.		90	Black fissile slate.
		Conway, Amherst and Brinfield.		1500 ?	Fine-grained, carbonaceous, muscovite-schist, and rusty mica-gneiss.
		Goshen.		600 ?	Dark, flaggy schist with interbedded gneiss.
		Unconformity.			
Ordovician.		Hawley.		600 ?	Green sericite-chlorito-schist, with beds of amphibolite and manganese silicates.
		Savoy.		1525 ?	Chloritic, quartzose sericite-schist, with beds of amphibolite, grading into feldspathic mica-schist.
		Chester.		900 ?	Epidotic hornblende-schist, with beds of magnetite and emery near top; contains beds of pyroxene rock, enstatite rock, and dolomite; often replaced by serpentine and steatite.
		Rowe.		1200 ?	Quartzose sericite-schist.
		Hoosic.		460	Feldspathic mica-schist.
		Unconformity.			
Cambrian.		Becket.[1]			White biotite-gneiss, locally grading into conglomerate.
Proterozoic.		Washington.		600 ?	Rusty biotite-gneiss. (Base not exposed).

SECTION IN WEST CENTRAL MASSACHUSETTS.[2]

[1] Becket gneiss now believed to be pre-Cambrian, partly igneous.
[2] Modified after B. K. Emerson, Holyoke, Mass. folio, U. S. Geol. Survey, 1898.

range into the Devonian system. All of the rocks are intruded by granite. In northern Maine early Devonian sandstones rest upon limestone carrying Silurian fossils.

Triassic Rocks. Along the Connecticut valley in Massachusetts and Connecticut and in a few localities farther southwest, Triassic beds equivalent to the Newark series of New Jersey rest in markt unconformity upon the folded Paleozoic formations. These younger strata consist chiefly of brown sandstone and red, black and green shale, with conglomerates prevalent near the bottom. They are generally interpreted as deposits made under subaerial conditions in a moderately dry climate. In the rocks they find the remains of plants and fishes, as well as foot-prints and even bones of carnivorous dinosaurs (*Anchisaurus*). No marine fossils have been detected. With the sediments are interbedded basic lava sills and flows, the latter showing unmistakable surface textures and occasionally associated with small deposits of fragmental volcanic material. These are the youngest volcanic rocks known in the eastern half of the United States.

Glacial Deposits. Thruout the entire district, deposits of glacial drift conceal most of the solid rock. In the mountainous northern and western

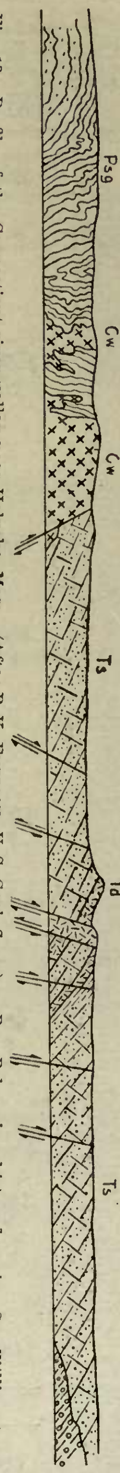


Fig. 13. Profile of the Connecticut river valley near Holyoke, Mass. (After B. K. Emerson, U. S. Geol. Surv.) — Psg, Paleozoic schist and gneiss; Cw, Williamstown granite, Carboniferous; Ts, Triassic sandstone and shale; Td, Triassic diabase, sills, dikes and flows. Length of profile, 29 km.

Fig. 14. Profile of folded Cambrian and Ordovician strata resting upon pre-Cambrian gneisses and schists in the Taconic mountains of western Massachusetts (after B. K. Emerson and others).

Fig. 15. Profile near Rockland, Maine. (After E. S. Bastin, U. S. Geol. Surv.) — Cp, Penobscot schists and slates intruded by granite and diorite; Cor, Rockland limestone, Cambro-Ordovician. Length of profile, 16 km.

parts of the region the drift is comparatively thin except in the valleys, but there it is sometimes unduly deep. In southeastern New England, the glacial deposits are more uniformly distributed and but little bed rock is exposed.

The glacial deposits consist chiefly of till, with occasional subordinate deposits of stratified sediments laid down in glacial lakes and rivers of the retreat stage.

Structure.

The Paleozoic and older rocks of New England are generally strongly folded and faulted. The individual beds of rock have been rendered slaty or schistose, or have completely recrystallized. The cleavage, folding, and other structures have a northerly trend, generally bearing somewhat to the east. All of the rocks have been invaded by batholiths and small intrusions of granitoid rocks. Altho the Triassic series has not been folded, it has been tilted eastward at angles of 10—25° and broken by many normal faults, of which some are large. It is reported that some of these faults have maximum displacements of more than 3000 meters. The strata and lava beds have been repeated by the faults in such a way as to considerably multiply the number of outcrops of the various formations.

The Post-Triassic sediments of New England are wholly undisturbed and largely unconsolidated.

History.

So little is definitly known about the pre-Cambrian rocks of the New England province that it is scarcely worth while to peer into that remote chapter of its history. There is evidence that before the Cambrian period the older structures were truncated by long continued erosion, and deep-seated rocks were exposed at the surface. Upon this foundation the early Paleozoic sediments were deposited somewhat intermittently but largely beneath the sea. Near the close of the Ordovician period these strata in addition to the older rocks, were closely folded along a belt extending from northern Maine south along the western border of New England into the Piedmont element, at least as far as Virginia. Probably all of the New England-Piedmont strip was deformed at that time.

The resulting period of erosion, altho effectiv, was not of long duration. Many parts of New England, particularly in the west, were subject to sedimentation again in the Silurian and Devonian periods. In the Devonian the rocks in Maine were again closely folded. There seems to be no trace of the Mississippian system within the political boundaries of New England, but in the continuation of the same province in eastern Canada, strata of that age are found resting on the truncated edges of Devonian and older rocks. In southeastern New England coal measures were formed during the Pennsylvanian, apparently under much the same conditions as prevailed in the Eastern Interior region, except in so far as local topographic differences favored the deposition of coarser sediments in Rhode Island. How extensiv these deposits originally were it is not now possible to say.

The final and perhaps greatest episode of folding followed the deposition of the Rhode Island coal measures and is thought to have been merely a part of the deformation of the whole eastern seaboard of North America about the close of the Permian period. This seems to have affected all of New England. Like the preceding orogenic disturbances, that of the Permian was markt by the intrusion of batholiths of granitic rock.

After the Appalachian revolution, as this period of folding has been called by J. D. Dana, the surface was eroded until the folds were completely truncated. Upon the surface of this complex mass of older rocks, the sediments of the Newark series were deposited in late Triassic time, the fossils indicating a relationship with the

European Rhaetic. The characteristics of these sediments indicate a semi-arid climate and terrestrial conditions not unlike those of many broad valleys in the Rocky Mountains at present. Volcanic eruptions from time to time are indicated by the basaltic flows and sills. Soon after the deposition of these Triassic beds, the New England region, like the northern part of the Piedmont element, was broken by an intricate series of normal faults. These may be readily recognized where they have disturbed the unaltered Triassic strata, but there can be little doubt that they are quite as numerous in many other parts of the district where the structure is now so complex as to make the recognition of faults a matter of extreme difficulty. This deformation cannot well have been later than early Jurassic time.

From the close of the Triassic to the Quaternary period the New England region seems to have been subject to the processes of erosion, the effects of which are noted in the discussion of physiography. The last Quaternary ice-sheet covered New England completely and doubtless presented a sea-wall of ice all along the coast. Since the glacial invasions there have been some notable changes of level, particularly a depression near the close of the glacial period, followed by an incomplete rising movement in more recent times.

Physiography.

Much of the New England region is an upland which has been dissected by a ramifying system of valleys into many hills and low mountains. The mountains are highest on the western and northern sides, sloping thence southeast to the Atlantic Ocean. All of the topography has recently been modified by glaciation.

According to W. M. Davis[1], the upland is a partially completed plain of terrestrial denudation (peneplain), upon which stand isolated hills not yet reduced to the general level. The mountains in the north and west are apparently more numerous and more continuous residual highlands (monadnocks). The highest of these monadnocks is Mt. Washington in New Hampshire, which reaches an elevation of 1918 meters above the sea. The peneplain corresponds to the Schooley or Kittatiny plain of the Appalachian region and, like it, was wrought largely in Mesozoic times, but persisted thru the Cretaceous period.

About the beginning of the Tertiary period, the Cretaceous peneplain was warpt and gently tilted southeastward. As a result, wide open valleys, such as those of the Connecticut river and Naragansett Bay, were excavated in the softer rocks, while the more resistant portions of the upland were dissected into a state of topographic maturity. Still more recently, apparently in the Quaternary period, renewed warping further rejuvenated the drainage and caused the incision of comparativly narrow valleys in the wider Tertiary depressions.

The invasion of the Quaternary ice sheets found the Tertiary topography thus hilly in the southeast, and mountainous in the northwest. The mountains and larger hills were slightly rounded and smoothened by glacial scouring, and at the same time the valleys were more or less clogged with deposits of till, which after the disappearance of the ice sheet, left drainage in a disordered condition. In the southeastern part of New England the deposits of till nearly or quite buried the hills and valleys in the rock. In such situations drumlins and small patches of terminal moraine give a specifically glacial character to the topography. The hookt peninsula of Cape Cod is part of a terminal moraine. In southern Maine certain areas have become celebrated for the abundance of eskers and other somewhat uncommon phases of stratified glacial drift.

In brief, the result of glaciation was a profound modification of the Tertiary topography of New England. To these changes are due the numerous lakes and

[1] Davis, W. M., in „The Physiography of the United States", New York, 1896.

disordered streams with their water-falls and gorges. The stony glacial soil on the one hand, joined with the abundant water power on the other, have combined to make New England a manufacturing rather than a farming district.

The present rugged coast line of New England is due to a comparativly recent submergence of the eastern portion of the province. A close study reveals the fact that there have been several oscillations of level within the Quaternary period, involving both elevation and depression.[1]

Seismicity.

Like other parts of eastern United States, New England is generally free from earthquakes. At infrequent intervals light shocks are felt, and a few have been strong enough to attract some attention. None of those which are on record can be called destructiv. In the 18th century Boston was severely shaken on one occasion but the resulting damage was inconsiderable.

Piedmont Element.

General.

The Piedmont element is in effect a southwestward prolongation of the New England element. The prevailing rocks are metamorphosed and highly folded and are associated with many igneous intrusions. The formations are more largely of pre-Cambrian age than in the better known parts of New England, but, as investigation proceeds, more and more bodies of altered Paleozoic sediments are being discovered in the Piedmont.

The orographic province is very nearly coincident with the Piedmont plateau already described as a topographic feature, but includes also the Unaka and other mountains. On the west it is hemmed in by the Appalachian mountains with their folded and but little altered Paleozoic strata. On the east and south it is enclosed by the soft sediments of the Atlantic-Gulf coastal plain.

Stratigraphy.

Metamorphic Series. As in the New England region, the structure of the rocks in the Piedmont belt is so complex that it has been elucidated only in the few small districts where it has been most carefully studied. In the mountains of North Carolina, A. Keith distinguisht a twisted complex of mica and hornblende schists injected by gneissic granites and pegmatites, which are in turn intruded by granites, serpentine, gabbro and other igneous rocks. Even in the oldest body of schist there are lenses of marble, doubtless of sedimentary origin. Most of these schistose formations are referred to the Archean, while certain altered volcanic effusivs are thought to belong to the Algonkian system.

In the northern part of the Piedmont element, from Virginia to eastern Pennsylvania, there are similar pre-Cambrian schists and gneisses intruded by granitoid rocks. The younger schists appear to be clearly of sedimentary derivation. At South Mountain in Pennsylvania the pre-Cambrian consists largely of metamorphosed rhyolitic and basaltic flows in which the original volcanic structures are still partly preserved. The studies of F. Bascom, N. H. Darton, E. B. Matthews and others have also disclosed Paleozoic rocks as constituents of the schistose series. These beds are quartzites, slates and mica-schists, from which in a few places Cambrian and Ordovician fossils have been obtained. They are evidently a southward continuation of the similar formations of western New England.

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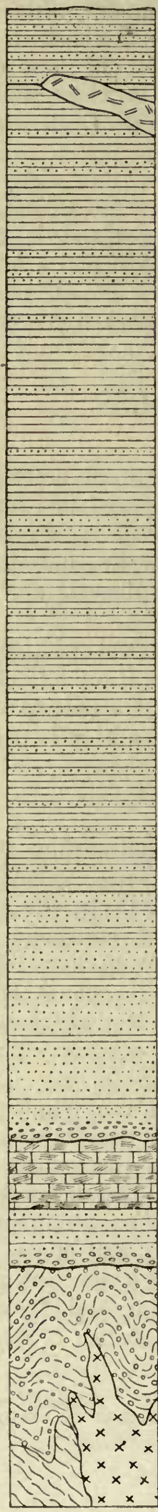
[1] C. A. Davis finds evidence that the coast near Boston is even now sinking. Econ. Geol. October-November, 1910

Per.	Div.	Formation.	Strata.	M.	Description.
Post-Triassic.				250 +	Alternating sands and clays partly marine, representing Comanchean, Cretaceous, Miocene and Pleistocene periods.
		Unconformity.			
Triassic.					Dikes and sills of diabase.
Triassic.		Brunswick.		1835 +	Soft red shale, with local beds of red sandstone.
Triassic.		Lockatong.		550—1100	Dark colored argillite and fine-grained slabby sandstone.
Triassic.		Stockton.		700—950	Gray, yellowish and reddish brown sandstone, mostly massiv and moderately hard. Basal beds arkosic and locally conglomeratic. Red shale intercalations at various horizons.
		Unconformity.			
Ordovician.		Shenandoah.		460 +	Crystalline, siliceous, magnesian blue limestone. (*Maclurea, Cyrtoceras*, etc.).
Cambrian.		Chickies.		400 +	Quartz conglomerate and quartz schist. (*Scolithus linearis*).
		Unconformity.			
Pre-Cambrian.		Wissahickon.		600 +	Banded quartz-feldspar rock with an excess of biotite. Small isolated body of crystalline white limestone. Granite and gabbro intrusiv in pre-Cambrian gneisses.
Pre-Cambrian.		Baltimore.		?	Banded quartz-feldspar rock.



SECTION NEAR TRENTON, NEW JERSEY.[1]

[1] After F. Bascom, N. H. Darton, H. B. Kümmel, and others, U. S. Geol. Survey, 1909.

In the Carolinas also considerable bodies of sedimentary strata are infolded with the Archean schists and gneisses. The upper portion contains fossils of Cambrian and Ordovician age, but the great body of sediments, often called the Ocoee series, constitutes a downward extension beneath the *Olenellus* horizon. This part is regarded by Keith[1] as also Cambrian, but by Van Hise and Leith[2] as late Algonkian. The metamorphism of these sediments increases to the south and east, so that in Georgia and eastern Alabama the Ocoee series is represented by various schists with lenses of marble. In these schists Smith[3] found fossil plants probably of Carboniferous age.

Triassic Sediments and Lavas. Small patches of the Newark formation similar in all essential respects to the Triassic of southern New England (see p. 88) are found inlaid upon the prevailing gneissic rocks from New Jersey south to North Carolina. They are preserved in thick wedges (locally more than 4000 meters) only where they have been faulted down into the older formations. The prevailing rocks are reddish or black shales and sandstones,—the latter generally feldspathic in composition. As in New England, the Triassic beds of the Piedmont province are associated with contemporaneous basaltic flows and sills, and in southern Virginia, the Newark rocks contain a few small coal seams which are of minable thickness.

Younger Sediments. Formations younger than the Triassic do

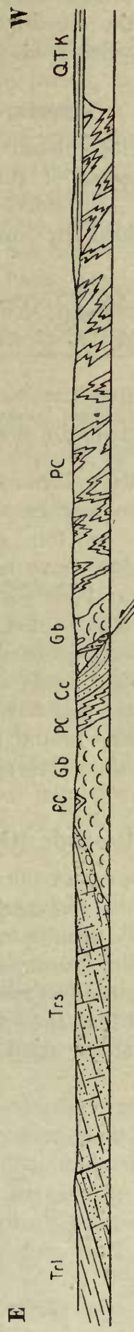


Fig. 16. East-west profile near Trenton, N. J. (After F. Bascom and others, U. S. Geol. Surv.) — PC, Pre-Cambrian schist and gneiss; Gb, gabbro intruded into PC; Cc, Chickies quartzite, Cambrian; Trs, Stockton sandstone, Triassic; Trl, Lockatong shale, Triassic; QTK, Quaternary, Tertiary and Cretaceous sediments of the coastal plain. Length of profile about 22 km.

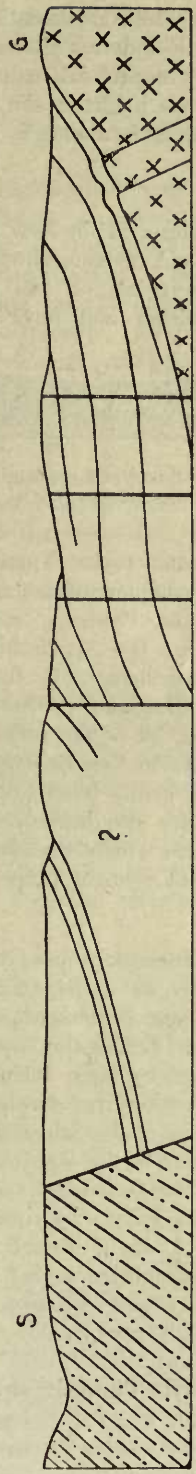


Fig. 17. Profile near Richmond, Virginia, showing a tilted wedge of Triassic coal-bearing sediments, faulted down into pre-Silurian schists (S), and granite (G). (After Shaler and Woodworth, U. S. Geol. Surv.)

[1] Keith, A., Asheville, N. C. Folio (No. 116). Geol. Atlas U. S., U. S. Geol. Surv., 1904.

[2] Van Hise, C. R., and Leith, C. K., Pre-Cambrian Geology of North America. U. S. Geol. Survey, Bull. 360, 1909.

[3] Smith, E. A., Carboniferous Fossils in the Ocoee slates in Alabama, Science, new series, vol. 18, 1903, pp. 244—246.

not constitute an essential part of the Piedmont element. In the extreme north the glacial drift covers the northern portion of New Jersey and Pennsylvania. Farther south, the only superficial materials are outliers of Cretaceous and Tertiary beds which have been detacht from the coastal plain on the east by erosion. Of these the Lafayette (Pliocene?) formation is the most widespread.

Structure.

Here, as in New England, the Paleozoic and older rocks have been intensely folded and metamorphosed. The trend of the structures is roughly parallel to the Atlantic coast, or east of north. The oldest rocks have been repeatedly comprest and twisted and have been invaded by innumerable dikes, stocks and batholiths

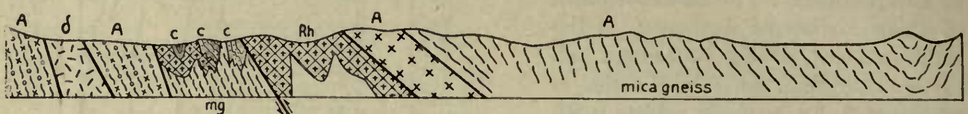


Fig. 18. Profile of mountains in Western North Carolina, showing Archean gneiss and schist (A, mg), with intruded or infolded bodies of Algonkian altered igneous rocks (Rb) and Cambrian quartzite (c). (After A. Keith, U. S. Geol. Survey).

of igneous rock. These in turn have been subjected to more folding, leaving an intricate complex of metamorphic and igneous rocks, standing in upright isoclinal folds.

The Paleozoic strata, altho on the whole but little metamorphosed on the side near the Appalachian mountains, have been closely folded and are broken along huge overthrusts. In the argillaceous beds slaty cleavage is prevalent, and in some parts of the Piedmont province, particularly in the northeastern and extreme southwestern portions, all of the rocks are decidedly schistose.

As in New England, the younger rocks are but little disturbed. Those of Triassic age are gently tilted toward the west and have been broken by occasional normal faults. There are also intrusiv sills of diabase of the same age. The Comanchean and younger rocks are wholly undisturbed, but these belong rather to the Coastal Plain than to the Piedmont element proper.

Geologic History.

The early pre-Cambrian events of the Piedmont region are wrapt in the same obscurity as in New England. That sediments were deposited there, and that there were some contemporaneous volcanic eruptions, is indicated by the studies of Keith and Bascom. Before the deposition of the Ocoee series, all of the older rocks were folded, disturbed by large intrusions of granitic rocks, and intensely metamorphosed. The entire region was deeply eroded so that the basal Ocoee strata rest upon many different members of the schistose series. This period of erosion is generally referred to the later part of the Proterozoic era.

The Ocoee series of the South represents the deposition of ill assorted sediments, probably largely by rivers deriving their material from an extensiv southeastern landmass. These processes were in operation in late Algonkian or earliest Cambrian times. In the Cambrian period, if not before, the sea invaded the Piedmont region, and marine strata ranging in age from lower Cambrian to Ordovician were deposited in essentially conformable sequence. How much of the region was submerged is not yet known.

The Taconic revolution, the effects of which are prominent in western New England, was felt at least as far as southern Virginia and perhaps to Alabama. The Ordovician strata in central Virginia are intensely folded and generally metamorphosed past recognition.

From the Ordovician to the Permian period the Piedmont element seems to have been the site of a land-mass of varying size. This is indicated by the abundant sediments which were deposited along its western shore, in the Appalachian geosyncline. Hints of the topographic changes thru which such a land mass must have past, may be gleaned from the varying character of these sediments. There is some evidence of orogenic disturbance in the Devonian period, as in Maine.

About the close of the Permian period, the Piedmont region, in common with the entire Atlantic slope, was again folded in a northeast-southwest direction, and by the disappearance of the Appalachian trough became attacht to the great interior land-mass. Since that event its history has been one of comparativ quiet. There was warping of the surface during the Triassic period, accompanied by alluviation of the depressed areas now occupied in part by the bodies of Newark sediments. At the same time, as in New England, outflows of basic lava, the last volcanic eruptions of the region, took place. The volcanic episode was followed quickly by tensional fracturing, the effects of which are best known as the faults in the Newark rocks, but which certainly affected a far larger area.

In the later Mesozoic periods the deprest eastern border of the Piedmont element, which had been eroded to a featureless lowland, was covered with marine sediments. This covering has been but partially stript off, and therefore still conceals the limits on the eastern side. The later history of the district is concerned chiefly with the modifications of topography by erosion, save for some temporary inundations of its borders in the Miocene period.

Physiography.

Topography. In the central and northern parts of the district, the Piedmont element is a low hilly plateau. The hills are obviously due to the mature development of a system of branching valleys, rather than to special differences in the hardness of the rocks. The hills have subdued outlines and are either well wooded or cultivated. In New Jersey and Virginia, the hard beds of Triassic trap rock stand out as somewhat more conspicuous ridges with scarp fronts. In the far south, on the other hand, masses of pre-Cambrian granite and Ocoee quartzite rise in the form of high mountain groups. One of these peaks, Mt. Mitchell, in North Carolina, is the most elevated point in eastern United States (2022 meters above sea level).

Physiographic History. Aside from the fact that the Piedmont element has not been glaciated, the history of its topography is much like that of New England. Before the deposition of the Comanchean (Lower Cretaceous) strata, the region had been reduced by the processes of erosion to a monotonous plain above which rose but few residual hills. Exception must be made in the case of the Unaka and other mountains of the Carolina region, which seem to have been so situated with reference to drainage lines that they were never effaced but on the contrary persisted as rugged mountain groups 1000 or more meters in height. The old worn-down plain with its residual elevations remained and was slowly extended during the Cretaceous period.

At some time in the Tertiary period, irregular doming, amounting locally to as much as 1000 meters, quickened the activity of the streams and enabled them to cut down into the softer rocks. During the succeeding period of quiescence, the new valleys were reduced to grade (slope of equilibrium) and were widened until only the most resistant formations stood out as ridges. The readjustment of the streams to the rock structure involved many interesting bits of physiographic history which cannot be detailed in this short account. Many large streams which formerly flowed across the Piedmont element from the Appalachian mountains were beheaded by a few master streams such as the Potomac, and were thus greatly reduced in importance. The Tertiary peneplain has since been trencht by the streams in consequence of Quaternary

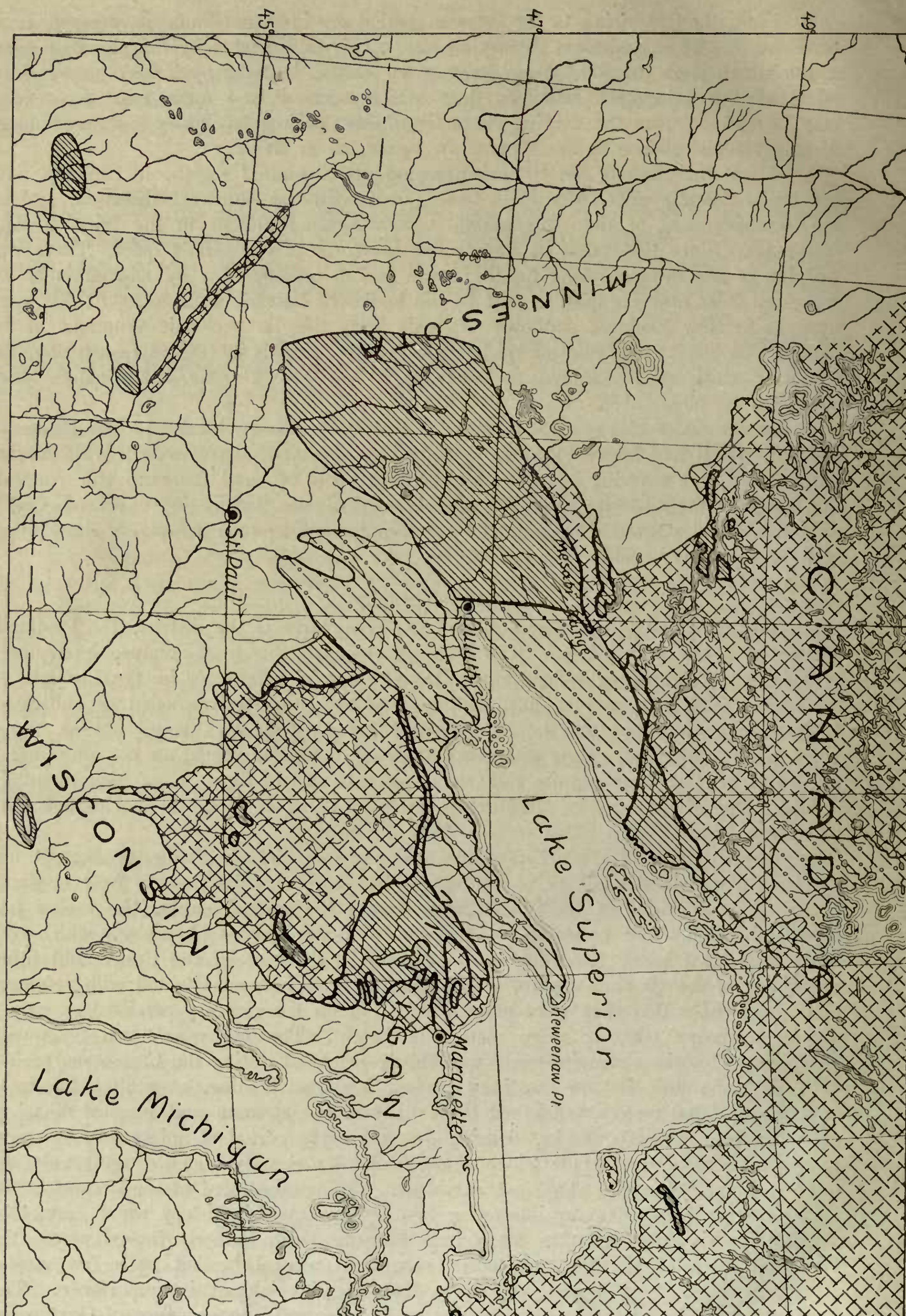


Fig. 19. Geologic sketch map of the Lake Superior district. (Modified after C. R. Van Hise and C. K. Leith, U. S. Geol. Surv.)

changes of level. In this way the present hilly topography has been produced. Within historic times the heavy forests which formerly covered the Piedmont surface have been in process of destruction. This has permitted the more rapid erosion of the soil from the steep slopes,—changes which will result, on the one hand, in laying bare the underlying rocks over large areas and on the other in choking the river bottoms with an undue influx of sand and mud.

Seismicity.

The Piedmont province in hardly more subject to earthquakes than the north-eastern states. In historic times it has experienced infrequent mild shocks, a very few of which have been strong enough to shake loose objects from their places and even to crack the walls of houses.

Lake Superior Element.

General.

The prevailing rocks of the Lake Superior district are more or less metamorphic terranes of pre-Cambrian age. Thru the work of R. D. Irving, C. R. Van Hise, and many others, the intricate structure of this region has been more thoroly workt out than that of most other pre-Cambrian districts. It now appears that there is a large complex synclinorium flankt by several smaller folds and surrounded by the under-lying Archean rocks. To the west and south the outcrops of the older terranes disappear beneath the flat-lying Paleozoic sedimentary rocks; but northward and east-ward the pre-Cambrian formations extend into the vast Canadian complex of ancient rocks, of which in truth they are a part.

Stratigraphy.

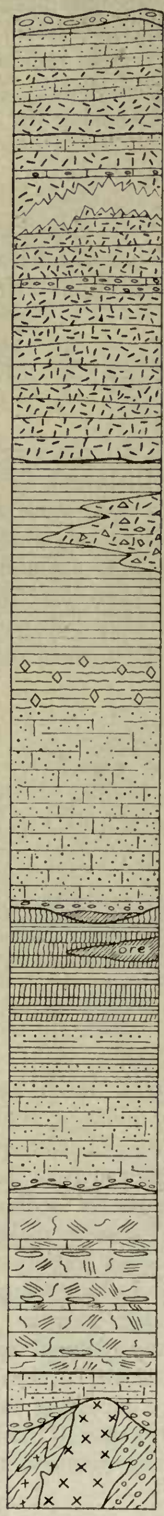
Altho there are still differences of opinion in regard to some points, the succession of strata in the Lake Superior element is now fairly well establisht. Following the decision of the International Committee of 1905, we have the following subdivisions, with the oldest at the bottom.

Paleozoic		
Algonkian	Keweenawan	
	Huronian	Upper
		Middle
		Lower
Archean	Laurentian (intrusive)	
	Keewatin	

Archeozoic. The Archean or Basement Complex, as it has been called in earlier times, consists largely of greenish schists. Over much of the district the origin of these schists is problematical, but on the north shore of Lake Superior and in some other localities the greenstones have apparently been derived from basic igneous flows and breccias. Beds of iron ore and slate, unquestionably of sedimentary origin, are infolded and probably interbedded with these schistose volcanic rocks.

The green schists are complexly intruded by a great variety of plutonic rocks, among which the acidic species predominate. They include granites, syenites and porphyries. Some of them have been metamorphosed into gneisses, while others are not notably changed. It is evident that they are of very different ages and some are doubtless Proterozoic. To this acidic intrusiv phase of the Archean is now applied the term "Laurentian." The gneisses are considered typical of the Laurentian.

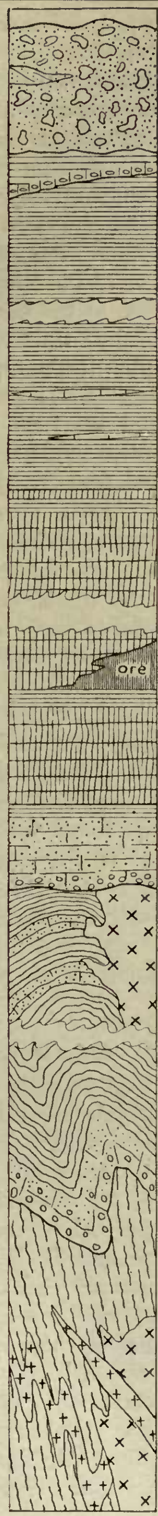
Proterozoic. The predominating igneous and generally much metamorphosed rocks of the Archean system are contrasted with a thick younger succession of beds



Per.	Div.	Formation.	Strata.	M.	Description.
Quat.	Upper.	Wisconsin.			Glacial drift.
Algonkian (Proterozoic).	Keweenawan.[1]				Red sandstone.
				10000—15000	Basic flows, with interbedded conglomerate and red sandstone.
		— Unconformity. —			
	Upper Huronian.	Michigamme.		?	Slate, locally replaced by Clarksburg volcanic flows and breccia.
		Bijiki.		150+	Green amphibole-magnetite-schist.
		Goodrich.		500+	Quartzite, containing local iron ore bodies at its base.
		— Unconformity. —			
	Middle Huronian.	Negaunee.		300±	Jaspillite, slate and iron ore.
		Siamo.		200±	Gray slate and graywacke.
		Ajibik.		210—270	Quartzite, pure and vitreous, with basal conglomerate.
		— Unconformity. —			
	Lower Huronian.	Wewe.		30+	Red gray and yellow slate.
		Kona.		420±	White to pink dolomite, with beds of chert, slate and quartzite.
		Mesnard.		50—250	White quartzite with basal conglomerate.
		— Unconformity. —			
Archean.		Kitchi and Mona.			Biotitic and hornblendic schists, in a few places containing narrow bands of jaspillite and iron ore. Intruded by granite and granite-gneiss.

SECTION IN THE MARQUETTE DISTRICT, MICHIGAN.[2]

[1] Exposed west of the Marquette region. — [2] After C. R. Van Hise and W. S. Bayley.



Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.		Wisconsin.		50—70	Glacial drift of the Wisconsin epoch.
		Unconformity.			
Cretaceous.		Colorado (?).		5—15	Gray clay-shale, with basal conglomerate. (Foraminifera).
		Unconformity.			
Algonkian (Proterozoic).	Keweenawan.				Great basal gabbro and granite, intruded into upper Huronian beds.
	Upper Huronian.	Virginia.		?	Massiv argillite and slate, with beds of impure limestone. Thickness unknown but great.
		Biwabik.		200—300	Ferruginous chert, with slate and iron ore.
		Palms.		20—60	Slate, quartzite and basal conglomerate.
		Unconformity.			
	Lower-Middle Huronian.			1000—1500 ?	Slate, graywacke and conglomerate, intruded by granite.
		Unconformity.			
Archean.				?	Granites and porphyries, intrusiv into older schists Greenstones, green schists, and porphyries.

GENERAL SECTION IN THE MESABI DISTRICT, MICH.[1]

[1] Modified after C. K. Leith, U. S. Geol. Survey, 1903.

Fig. 21. Geologic profile across the Lake Superior district. — Length, about 450 km. (After Van Hise and Leith, U. S. Geol. Surv.) Ar, Archean; H, Huronian; K, Keweenawan; C, Cambrian.

Fig. 20. Profile of the Marquette, Mich. district. (After C. R. Van Hise and W. S. Bailey): N, Negaunee formation; S, Siamo slate; A, Ajibik quartzite; W, Wewe slate; K, Kona dolomite; G, granite intruded into the Archean only; Gn, Archean gneiss.

which are dominantly of sedimentary origin,—locally known as the Algonkian. The Algonkian rocks comprise quartzites, slates, and dolomites, with beds of iron ore and, in some places, thick masses of surface volcanic rocks. Wherever the base of this series has been clearl yseen, the lowest bed rests unconformably upon the Archean. In some of the better known localities the Proterozoic succession has been subdivided into several distinct systems, as in the Marquette district, where there are four, and in the Mesabi, where there are at least two. In some other regions, however, the rocks are so highly metamorphosed that no subdivision seems possible. The lower and largely sedimentary portion of the Lake Superior Proterozoic group has been called the Huronian system. Above this and separated from it by an unconformity is the Keweenawan, which is made up largely of flows of basic igneous rocks. Layers of sandstone and conglomerate are intercalated between the lava beds, here and there, and the upper portion of the series consists very largely of reddish ill assorted sediments now believed to be subaerial deposits.

Upon the deeply eroded surface of the folded pre-Cambrian strata, Paleozoic beds lie in almost horizontal attitude. They have been entirely removed from the northern and central portion of the district but are found in outliers of increasing size and number as the edge of the continuous Paleozoic outcrop is approacht on the south. In the west and south the beds are apparently of Upper Cambrian age, but in northern Michigan the basal formation is as young as the middle Ordovician.

Structure.

Folding and Faulting. With the exception of the Paleozoic strata, all of the rocks in the Lake Superior district have been folded. The most conspicuous structural feature is a great complex syncline, the central part of which is now concealed by Lake Superior. The general trend of this syncline is about N. 70° E. The fold is unsymmetrical, the beds having a gentle dip on the north, and a steep dip on the south. South of the syncline there are minor folds with the same trend and evidently made at the same time. An important zone of overthrust faulting flanks the south side of Lake Superior thru northern Wisconsin and part of Michigan. It affects chiefly the Keweenawan rocks.

The Archean rocks have been, as would be expected, far more intensely deformed than any of the later formations. The Huronian rocks have all been closely folded on the south side of Lake Superior, but on the north only the Lower Huronian is much plicated. The Keweenawan beds have been even less deformed, being merely tilted or gently folded even on the south side of the syncline.

Igneous Intrusions. Bodies of intrusiv igneous rock of considerable size have locally disturbed the folded terranes. Northern Wisconsin consists largely of granitic rocks which appear to constitute a complex batholith intruded along the south side of the Lake Superior syncline. In the Mesabi range, west of Duluth, and in other places, smaller bosses of granite have invaded the Algonkian sediments. Round about these masses, and in some cases as much as 20 miles from the outcrop, the rocks have been highly metamorphosed. Formations which are merely slate and quartzite in other parts of the district have there been changed into schists, and the included iron-bearing terranes have become useless amphibole-magnetite rocks. Along the south side of Lake Superior there are also many small intrusiv bodies of gabbro, granite, diorite, and porphyries. In the neighborhood of some of these the sediments are much altered. North of the western end of Lake Superior, the Duluth gabbro,—a great lenticular mass,—is interpreted as a massiv sill or laccolith intruded into the upper Huronian sediments during the Keweenawan period.

Geologic History.

Archeozoic. In the obscurity of the geological record as preserved in the highly folded and metamorphosed Archean rocks of the Lake Superior district, only a few of the larger facts have been discerned. That there were many successiv volcanic eruptions is clearly indicated by the succession of basic and occasionally acid flows in the Keewatin series. Between eruptions local deposits of mud and ferruginous sediments were laid down, eventually to become slate and iron ore. That there were repeated intrusions of magmas of varying composition is shown by the variety of plutonic bodies and their mutual relations. Some of these are now metamorphosed, while others are not,—indicating that there were successiv episodes of deformation. That there was intense folding, now and then, under the weight of a heavy cover of superimposed rocks, may be inferred with confidence from the intricately twisted and contorted laminae and from the highly metamorphosed character of much of the Archean mass. Before the oldest recognized Proterozoic sediments were deposited, however, the region must have been subjected to erosion for a time long enough to permit the uncovering of the rocks which had been thus metamorphosed at greater depths.

Proterozoic. During the Proterozoic era the volcanic activities were less dominant than in the Archean. Over a wide area sediments were deposited in thicknesses which are great as compared with those of some later eras. Most of these sediments were distinctly land-derived, the limestones being subordinate to the clastic matter. The interpretation of the Algonkian sediments has not yet been carried far. It has usually been supposed in the past that these sediments were of marine origin. More recently several students of the region have shown that the conglomerates and sandstones of the Keweenawan, and some considerable portions of the Huronian, were probably formed on land rather than in the sea. The evidence consists of abundant ripple marks and sun cracks, together with the reddish color which so often accompanies the deposits in arid and semiarid regions. With these may be mentioned the almost complete absence of traces of life in these beds.

Contemporaneous volcanic activity continued in one place or another at intervals thru the Proterozoic era, as is indicated by the thick volcanic breccias and flows in the Huronian series on the south side of Lake Superior, and by the great Keweenawan fissure flows of the same region. There were also episodes of deformation now and

then, which involved the emergence of regions that had been submerged, the shifting of the sites of sedimentation, and the folding and faulting of strata previously deposited. These facts are recorded chiefly in the prominent unconformities which have been found to separate the major divisions of the Proterozoic group. Doubtless there were long periods, comparable in duration to those known from the sediments, during which the Lake Superior region was subject to erosion rather than deposition.

Post-Algonkian. After the last period of deformation, when the Keweenawan beds had been bent into their present synclinal attitude and many granitic intrusions invaded the region, orogenic disturbances ceast and have never been renewed. Before the Cambrian period the region seems to have remained as land for so long a time that all of the pre-existing topographic features were worn low. Weidman[1] finds evidence that the pre-Cambrian rocks in central Wisconsin were denuded to a featureless plain covered with a residual soil which is locally preserved beneath the overlying Paleozoic deposits. Evidence of similar base-levelling has been found at many points in the Lake Superior district and in Canada. Eventually in the early Paleozoic periods a thin sheet of sediments was spread over much if not over all of the district. This deposition seems to have accompanied the slow encroachment of the Cambro-Ordovician sea, but it is probable that much of the basal formation was deposited not in the sea, but on low plains adjacent. These beds contain few if any fossils, and have many of the marks of deposition in shallow shifting streams.

The subsequent history of the Lake Superior region is essentially that of the interior region to the south and west. During the later Paleozoic and early Mesozoic periods it is probable that the region was the site of an extensiv land and subject to continual denudation. In consequence of this denudation, such Paleozoic beds as may have been deposited over the central and northern portion of the district were removed and only scattered outliers were left here and there on hill-tops around the border. During the Cretaceous period the west side of the district was entered by the great Cretaceous mediterranean of North America, the shore of which must have crost the district,—probably from north to south. This was but a temporary submergence, and, ever since the Cretaceous sea retired, the district seems to have been continually a low-lying land, much as it is today.

The province was completely covered by the great Quaternary ice-sheets, which descended from Canada. The disappearance of the last of these ice-sheets was so recent that scarcely any noteworthy changes have taken place since then. Everywhere one may now see the scored and rounded hills of freshly cleaned rock, more or less buried by the rough deposits of glacial till and the sandy beds of outwash.

Physiography.

According to L. Martin[2], who has written a general account of the physiography of this district, the Lake Superior region contains three chief topographic divisions: the highlands grouped around Lake Superior, the lowland to the south and west, and the basin occupied by the Lake itself. The second of these merges into the element which is next to be considered, i. e., that of the broad interior lowlands.

The highlands may be divided into two groups, one along the northwest side of Lake Superior, and another much broader area, south of the lake. These highlands mark the exposures of the more resistant pre-Cambrian rocks. The topography of the highlands is that of a gently undulating plateau, about 300—400 meters above sea level. Over wide areas the surface is so nearly plane that a level sky-line is characteristic.

[1] Weidman, S., The Geology of North Central Wisconsin, Wis. Geol. and Nat. Hist. Survey, Bull. 16, 1907.

[2] Van Hise, C. R., and Leith, C. K., The Geology of the Lake Superior Region. U. S. Geol. Survey, Mon. 52, 1911 (Chapter IV by L. Martin).

Here and there, however, isolated low hills rise above the general horizon, and wide valleys with gentle slopes have been excavated in the plateau surface. The rocks beneath the plain vary in their character and are complexly folded. It is believed that the region was once mountainous but that it has been worn down to a nearly featureless lowland and later raised into a low plateau. The hills and valleys follow roughly the structure of the underlying rocks except in so far as they have been modified by glaciation.

This correspondence between topography and rock structure was doubtless much plainer before the coming of the Quaternary ice sheets. The forms of the hills have been considerably modified by glacial erosion, and in the valleys irregular deposits of glacial drift form obstructions. Upon this modified surface, lakes and swamps are abundant and the courses of the individual streams are erratic. No residual soil, such as is characteristic of most old-age plains, is left in this region. That it was once there but has been carried away in the course of glaciation is undoubted.

Over the Paleozoic rocks and some of the softer pre-Cambrian formations the land has been worn considerably lower than the plateau surface of the highlands. Relief there is generally slight and, except where there have been post-glacial changes of drainage, the valleys are wide and open. The interstream divides are generally flat-topt or consist of long low monoclinal ridges.

Lake Superior itself lies in a long trough with abrupt slopes on the north and south. The lowest point in this depression is more than 120 meters below sea level. West of the lake the trough may be traced for a considerable distance between the highlands of crystalline rocks on the north and south. The bedded rocks on either side of the basin dip toward the trough, indicating plainly a synclinal structure. The syncline is, however, of late Algonkian age, for the Paleozoic rocks which adhere to the sides of the basin in some localities are essentially horizontal.

The synclinal depression is commonly supposed to have been filled by the deposition of horizontal Paleozoic sediments. In post-Paleozoic times the basin was partly re-excavated, probably because of the comparativly weak character of the Paleozoic strata. In the Quaternary period the basin was occupied by a lobe of the Canadian ice-sheet and by this agency was probably deepened and modified in some details. In the same way its western end became choked with glacial debris. There is clear evidence that the surface of the district has been subject to differential changes of level since glaciation and to more pronounced warping before glaciation, but it is not known in what measure deformation is responsible for the Lake Superior basin as it now exists.

Seismicity.

The province is seismically very quiet. No destructive earthquakes have been recorded, and very few that have been even perceptible have occurred within the last two centuries.

Interior Lowlands Element.

General.

The vast central region of the United States is characterized by rocks which have been but little disturbed and over most of which a surface of low relief has developt. Plains are intersperst with low hilly tracts or plateaus of moderate relief. In the east the rocks are chiefly of Paleozoic age, while on the west Mesozoic formations, with a veneer of Tertiary beds, predominate.

On the north the lowlands wrap around the Lake Superior and Adirondack highlands. Eastward they grade almost insensibly into the plateaus of horizontal Paleozoic rocks which flank the Appalachian mountains. On the south, likewise, they pass

gradually into the coastal plain, except where they are hemmed in by the mountains of the Ouachita element. On the west the plains rise with a long gentle slope to the plateaus which form the base of the Rocky Mountains. This slope is called the „Great Plains“.

Fig. 22. Sketch map of the Interior Lowlands Element.

The climatic differences influence the character of the surface in such a way as to give much variety to different parts of the Interior Lowlands. The moist and hilly districts of the southeast are, or were, clad with dense deciduous forests. The Great Plains, under a sub-arid climate, are sparsely covered with grass; wind and rain readily attack the sod, expose the naked sand and clay, and locally even heap the sand into shifting dunes. In the less favored portions agriculture can be carried on only with the aid of irrigation. Between these two extremes lie the partly wooded and

partly prairie regions of the central states which constitute one of the greatest agricultural regions on the continent.

Stratigraphy.

In this immense region, rocks of nearly all ages from pre-Cambrian to Tertiary and Pleistocene are exposed. Even in some small districts a nearly complete section from bottom to top may be observed. Between different portions of the element there are great horizontal changes in the lithology of individual formations. Thus the Carboniferous is represented largely by sandstone and shale on the eastern border, while on the western edge limestone predominates. For this reason no general description of the formations applies to all parts of the province.

Pre-Cambrian. The ancient crystalline rocks reach the surface along the northern border of the lowlands, in the Adirondack mountains of New York[1], the Ozark plateau, central Texas, and a few other small areas; but elsewhere they are buried beneath Paleozoic sediments and are reacht only occasionally by deep borings.

The exposures in the north-central states belong properly to the Lake Superior element. Those of southeastern Missouri reveal granites and porphyries upon which rest small bodies of sedimentary rock and iron ore.

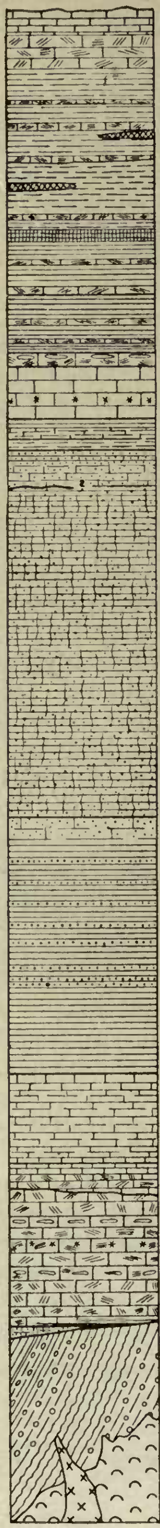
In the Adirondack mountains the pre-Cambrian rocks consist of crystalline limestone interbedded with schists and gneisses some of which are doubtless of sedimentary origin. Into these highly folded sedimentary beds a great central mass of gabbro has been intruded. The gabbro varies locally into pure anorthosite, and there are also other intrusiv rock such as granite and porphyries. On all sides except on the east, the Adirondack uplift is surrounded by nearly flat-lying Paleozoic sediments, usually with the upper Cambrian at the base. On the east side the Paleozoic beds are much folded.

Paleozoic. The Paleozoic beds are generally much thinner in this region than in the eastern and western portions of the country. The total thickness in the northeastern portion varies from 350—600 meters in northern Illinois to 2200—2700 meters in western New York and Pennsylvania. Farther south and southwest the complete thickness is seldom determinable, but in the Ozark region of Missouri it is about 400—500 meters. As compared with the formations of the Appalachian district those in the central lowlands contain a larger proportion of limestone and shale, with less sandstone and very little conglomerate.

At the base of the Paleozoic group there is nearly everywhere a sandstone varying from 10 to 300 meters in thickness. This is the Potsdam formation of New York and Wisconsin. It is believed to be of different ages in different places. In the south and west this basal sandstone contains a middle Cambrian fauna while in the north and east the fossils are generally of upper Cambrian types.

Upon this variable basal sandstone rests an alternation of limestones and shales with occasional sandy formations. The limestone is most abundant in the western portion of the lowlands, while shale and sandstone become more abundant east of the Mississippi River. This alternating series ranges from Cambrian to Mississippian (lower Carboniferous) in age. It includes five prominent limestone members. The lowest of these is a cherty dolomite of Cambro-Ordovician age,—the Lower Magnesian limestone of the upper Mississippi valley, or Beekmantown and subjacent beds in New York. This thickens southward where it appears in Missouri under various local names. The second is the Trenton limestone, a richly fossiliferous formation recognizable almost

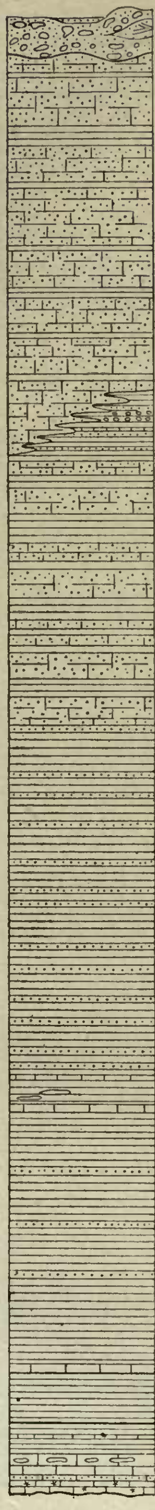
[1] The Adirondack mountains might be considered as a separate orographic element, but there is much reason to believe that they constitute merely a low dome-shaped uplift like the Ozark mountains of Missouri or the Cincinnati arch in Ohio. Geologically they seem distinct, merely because the ancient folded rocks have been so thoroly uncovered by the removal of the Paleozoic roof.



Per.	Div.	Formation.	M.	Description.
Silurian.	Upper or Cayugan.	Manlius.	2—25	Hard, dark blue limestone with thin partings of black bituminous matter. *(Spirifer vanuxemi, Leperditia alta).*
		Rondout.	0—14	Dark colored waterlime. Fossils rare. (*Lep. scalaris, Eurypterids*, etc.).
		Cobleskill.	2.5—3	Hard, dark limestone. *(Favosites niagarensis? Cyathophyllum hydraulicum, Spirifer crispus var. corallinensis).*
		Salina. Bertie.	35	Dark colored, argillaceous magnesian limestone. Fossils rare. (*Lingula, Orbiculoidea, Leperditia alta, Eurypterids.*
		Salina. Camillus.	210—420	Dark dolomite, gray marly shale and gypsum.
		Salina. Syracuse.		Rock salt.
		Salina. Vernon.		Red and green shales and thin dolomites.
		Salina. Pittsford.		Black shale and interbedded dolomites. *(Eurypterids).*
		Guelph.	14	Gray to dark gray dolomite with chert nodules above. *(Trematonotus alpheus, Monomorella noveboracum, Stromatopora galtensis).*
	Middle or Niagaran.	Lockport (Niagara).	45—60	Gray to white and brown limestone and dolomite with beds of bluish gray hydraulic cement-rock. *(Stromatopora concentrica, Favosites niagarensis, Halysites catenulatus).*
		Rochester.	21	Calcareous gray or brown shale with thin limestone layers. (*Dalmanella elegantula, Eucalyptocrinus, Dalmanites limulurus, Spirifer niagarensis*, etc.).
		Clinton.	36	Interbedded shale and limestone of various colors. (*Whitfieldella intermedia, Strophonella patenta, Calymene clintoni, Illaenus ioxus*, ètc.).
	Oswegan.	Medina.	10	Dark red to gray sandstone and sandy shale (fossils generally absent; *Lingula cuneata, Whitfieldella oblata, Arthrophycus harlani*,etc.).
		—Unconformity. (?)—		
Ordovician.	Cincinnatian.	Lewiston or (Lower Medina).	335	Bright red sandy shale. No fossils.
		Lorraine.	150—210	Alternate dark shale and gray sandstones with the Oswego gray sandstone at the top. Occasional beds of limestone. *(Plectorthis plicatella, Dalmanella testudinaria, Ambonychia radiata, Modiolopsis modiolaris, Cyrtolites ornatus).*
		Utica.	55—90	Hard slaty black, thin-bedded shale. (*Endoceras proteiforme, Triarthrus becki*, and graptolites).
	Mohawkian.	Trenton.	90 ±	Thin-bedded, dark bluish gray, compact limestones separated by thin shaly layers. (*Rafinesquina alternata, Orthis biforata, Ceraurus pleurexanthemus, Diplograptus amplexicaulis, Calymene callicephala*, etc.).
		Leroy ("Black Riv.")	2—4	Hard, fine-grained, dark limestone. (Large Orthocerata, *Columnaria, Streptelasma*).
		Lowville (Birdseye).	1—15	Bluish dove-colored pure limestone with spotted surface. *(Tetradium cellulosum. Phytopsis).*
	Canadian.	Tribes Hill.	12—15	Granular gray dolomite to thin-bedded blue limestone. *(Ophileta levata, Pleurotomaria hunterensis).*
		— Unconformity. —		
Cambrian.	Saratogian.	Little Falls.	135 ±	Mainly gray dolomite with some chert layers and containing crystals of dolomite, calcite and quartz in the upper part. (Cryptozoan reefs at several horizons and *Lingulepis acuminata* in basal shale).
		Potsdam.	0—25	Sandstone and limestone (not exposed).
		— Unconformity —		
Pre-Cambrian.				Various metamorphosed, sedimentary and igneous rocks with intrusiv bodies of granitic rock (exposed only in the northeast part).

SILURIAN AND OLDER FORMATIONS OF CENTRAL AND WESTERN NEW YORK.[1]

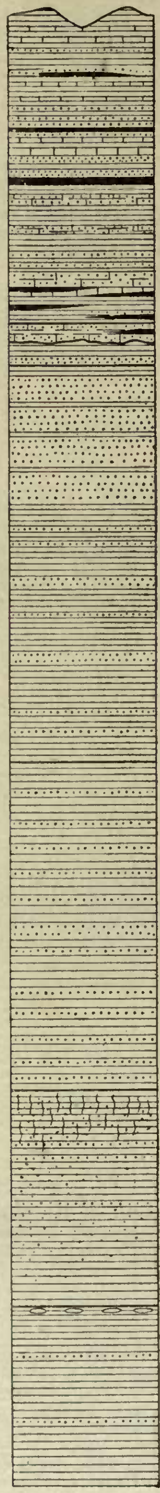
[1] Continued on next page.



Per.	Div.		Formation.	Strata.	M.	Description.
Quaternary.	Upper.		Wisconsin.		3–90	Glacial drift, etc.
			Unconformity.			
Devonian.	Upper.	Chautauquan.	Catskill.		150—600	Impure sandstone and shale of red, gray and greenish colors (fossils chiefly fishes, plants, and bivalve mollusks). The lower portion deposited contemporaneously with the Chemung formation.
Devonian.	Upper.	Chautauquan.	Chemung.		365—400	Thin-bedded sandstones alternating with drab to bluish shales. Flaggy sandstone at top with conglomerate lentils and thin limestone. *(Spirifer disjunctus, Douvillina mucronata, Productella lacrymosa, Leptodesma spinigerum, Pterinea chemungensis.)*
Devonian.	Upper.	Senecan.	Portage.		365—400	Dark bluish-gray shale and flaggy sandstone highly variable horizontally. (*Reticularia laevis, Paracyclas lirata, Spirifer mesistrialis, Plumalina plumaria, Manticoceras pattersoni*, etc.).
Devonian.	Upper.	Senecan.	Genesee.		23–42	Fissil black shale with thin limestone beds and concretions. Fossils rare. *(Lingula spatulata, Liorhynchus quadricostatus, Orbiculoidea lodensis.)*
Devonian.	Upper.	Senecan.	Tully.		8 +	Bluish-black limestone. (*Bronteus tullius, Hypothyris cuboides*, etc.).
Devonian.	Middle.	Erian.	Hamilton.		350	Gray to blue shale with thin beds of sandstone and a crinoidal limestone. (*Tropidoleptus carinatus, Vitulina pustulosa, Spirifer mucronatus, Chonetes carinatus*, abundant pelecypods, etc.)
Devonian.	Middle.	Erian.	Marcellus.		25–45	Black to olive fissil shale with occasional layers of dark limestone. *(Chonetes mucronatus, Strophalosia truncata, Orthoceras subulatum, Liorhynchus limitare).*
Devonian.	Middle.	Ulsterian.	Onondaga. (Corniferous).		22-25	Massiv bluish gray limestone with nodules and layers of chert. (*Proctus crassimarginatus, Platyceras dumosum, Conocardium trigonale, Spirif. gregarius, S. acuminatus*, many corals and fishes).
Devonian.	Lower.		Oriskany.		0–8	Coarse reddish to white quartz sandstone. (*Spirifer arenosus, Meristella lata, Hipparionyx proximus, Rennselaeria ovoides*, etc.
Devonian.	Lower.		Helderberg.		6–12	Dark gray coralline limestone (*Spirifer cyclopterus, Meristella laevis, Favosites*, etc.).
			Unconformity.			

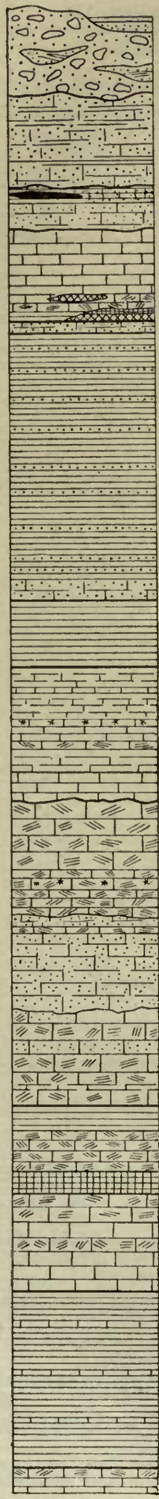
POST-SILURIAN FORMATIONS OF CENTRAL AND WESTERN NEW YORK.[1]

[1] Compiled largely from reports of New York State Geological Survey and revised by C. S. Prosser, 1911.

Per.	Div.	Formation.	Strata.	M.	Description.
Permian.	Dunkard.	Greene.		140	Shale and shaly sandstone with thin beds of limestone and impure coal. (*Taeniopteris, Callipteris, Sigillaria*, etc.).
		Washington.		120	Gray to black shale (plant fossils) and sandstone with several beds of blue to black limestone (Ostracods, gastropods, fish scales, etc.) and a little coal.
Pennsylvanian.		Monongahela.		120	Gray shale, in part calcareous and sandy. Beds of gray limestone and sandstone and several important coal seams, — the largest, or Pittsburg, seam lying at the base. (Fossil plants and minute Crustacea).
		Conemaugh.		235	Brown, gray and reddish shale and sandstone with a few thin beds of coal and limestone. (*Spirifer cameratus, Productus costatus*, etc.).
		Allegheny.		82	Gray and black shale with occasional beds of massiv gray sandstone and limestone. Several valuable seams of coal. (*Spirifer rockymontanus, Productus cora*, etc.).
		Pottsville.		40	Two beds of heavy sandstone, separated by shale, with thin limestone beds and locally a seam of coal. (*Chonetes mesolobus, Seminula argentea*, etc.).
		— Unconformity. —			
Mississippian.		Mauch Chunk.		55	Soft, red shale at top, coarse greenish to gray sandstone below.
		Pocono.		315	Gray sandy shale and coarse gray sandstone. Several beds of red shale. (Fossils very rare: — *Lingula*, plants.).
Devonian.		Catskill.		580	Red shale and sandstone, with thin beds of gray and green shale.
		Chemung.		730	Lower part gray and green shale with sandstone layers; upper part chocolate shale and sandstone. Fossils thruout. (*Spirifer disjunctus, S. mesistrialis, Atrypa hystrix*, etc.).
		Nunda.		490	Laminated pale brown clay shale at bottom, merging into greenish-gray, sandy shale with thin gray sandstone layers above. Few fossils. (*Liorhynchus mesocostalis, Paracardium doris*).
		Genesee		18	Soft black clay shale with limestone nodules.
		Hamilton.		400 +	Olive sandy and clay shale, with thin gray sandstone layers. (*Tropidoleptus carinatus, Chonetes mucronata, Grammysia arcuata*).

GENERALIZED SECTION IN THE ALLEGHANY PLATEAU OF WESTERN PENNSYLVANIA.[1]

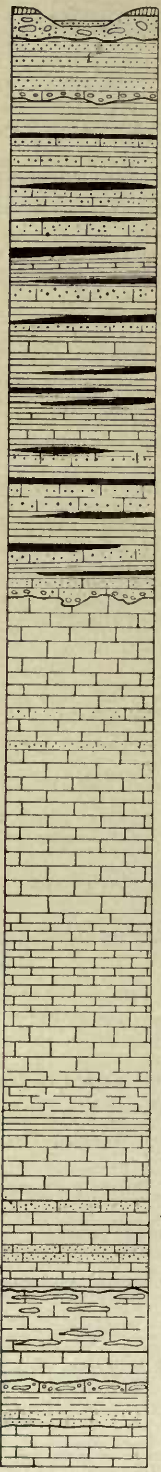
[1] Compiled from reports of M. R. Campbell and others, U. S. Geol. Survey.



Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.		Glacial drift, etc.		0—180	Till, gravel, sand, and clay.
		Unconformity.			
Pennsylvanian.		Woodville.		93	Gray sandstone grading into blue shale; layers of fire-clay.
		Unconformity.			
		Saginaw.		14	Sandy shale of various colors, with layers of fire-clay and coal.
		Unconformity.(??)			
Mississippian.		Parma. (?)		0—60	Porous sandstone saturated with brine.
		Unconformity. (?)			
		Grand Rapids.		93	Limestone, underlain or replaced by shale, dolomite and gypsum.
		Marshall.		15	Sandstone.
		Coldwater.		203—305	Blue arenaceous shale, with seams of fine-grained sandstone.
		Richmondville or Berea.		20	Sandstone.
Devonian.	Upper.	Antrim.		44—92	Black shale, often bituminous.
	Middle.	Traverse.		30—185	Some limestone in reefs, some dolomite, much blue argillaceous limestone, and shale.
		Dundee.		12—49	Light colored limestone.
		Unconformity.			
Silurian.	Upper.	Monroe. Lucas.		200—610	Dolomite.
		Amherstburg.			Porous brown dolomite. (Corals, brachiopods, and other fossils).
		Anderdon.			Light to dark brown limestone and friable dolomite. (*Stromatopora* and corals).
		Flat Rock.			Dark porous dolomite (corals).
		Unconformity.			
		Sylvania.			Very pure white cross-bedded sandstone, with rare beds of dolomite. *(Paracyclas)*.
		Unconformity.			
		Raisin River.			Thin-bedded gray dolomite and oolite, with tension cracks. (Mollusks and a few brachiopods).
		Put-in-Bay.			Dolomite. (Ostracods and brachiopods).
		Tymochtee.			Drab shale. (Fossils rare, chiefly ostracods).
		Greenfield.			Thin-bedded drab dolomite. (Ostracods and a few brachiopods).
		Salina. (?)			Rock salt.
	Lower and middle.	Niagara.		105	White dolomite and limestone.
Ordovician.	Middle and upper.	{ Lorraine. Utica.		185	Blue and black shale with some limestone.
		Trenton.		?	Dolomite and limestone.

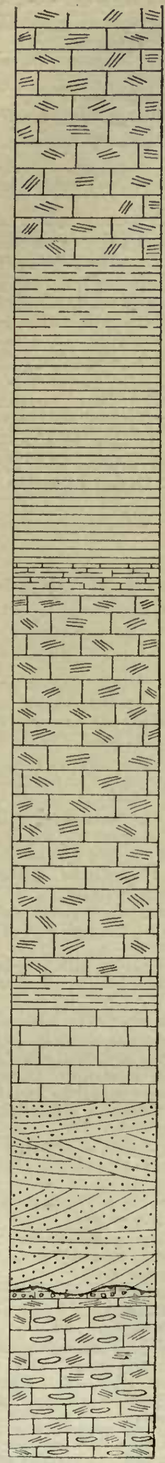
GENERAL SECTION OF STRATA IN SOUTHERN MICHIGAN.[1]

[1] Modified after A. C. Lane and others, Geol. Survey of Michigan, 1903—1910.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.	Upper.				Soil and modern alluvium.
		— Unconformity. —			
	Lower.	Illinoisan.		20–50	Glacial drift.
		Unconformity.			
Eocene.	Lower.			45	Sands, clays, and ferruginous conglomerate.
		— Unconformity. —			
Pennsylvanian.		Upper Coal Measures.		180—210	Shale, sandstone and limestone with seams of coal.
		Lower Coal Measures.		140—230	Shale, sandstone and limestone with seams of coal. Basal conglomerate.
		— Unconformity. —			
Mississippian.	Upper.	Chester (Kaskaskia).		245	Limestone with intercalated sandstone.
		St. Louis.		60-75	Thin-bedded limestone.
	Lower.	Osage.		60	Coarse limestone, often cross-bedded and shaly.
		Kinderhook.		15	Shale with interbedded limestone.
Devonian.	Upper.			12–26	Black to dark green shale (*Leiorhynchus globuliformis* and *Reticularia laevis*).
	Middle.			44-53	Dark gray to yellow crystalline and locally siliceous limestone (*Spirifer pennatus* and *Athyris spiriferoides*, *Strophalosia truncata* and other fossils in the upper part).
	Lower.	Clear Creek.		60—75	Thin-bedded gray and brown limestone and sandstone with Oriskany fossils (*Eatonia peculiaris*, *Anaplotheca flabellites*, *Phacops cristata*, etc.).
		— Unconformity. —			
		Helderbergian.		45 +	Shaly limestone and chert (*Uncinulus nobilis ?*, *Spirifer perlamellosus*, *Meristella laevis*, etc.).
Silurian.	Mid.	Niagara.		23	Gray to pink limestone with *Favosites favosus*, *Spirifer sp.* and *Triplecia ortoni*.
		— Unconformity. —			
	Low.	Cape Girardeau.		1—14	Limestone, dark and partly oolitic, with much chert. (*Rafinesquina mesacosta*, *Dalmanites danae*).
Ordovician.	Upper.	Richmond.		27	Gray shale and sandstone (*Rhynchotrema*, *Zygospira* and *Strophomena*).
		— Unconformity.(?) —			
	Mid.	Trenton.		30 +	Light crystalline limestone (*Receptaculites oweni*, *Platystrophia biforata*, *Plectorthis plicatella*, *Platemetopus cucullus*, etc.).

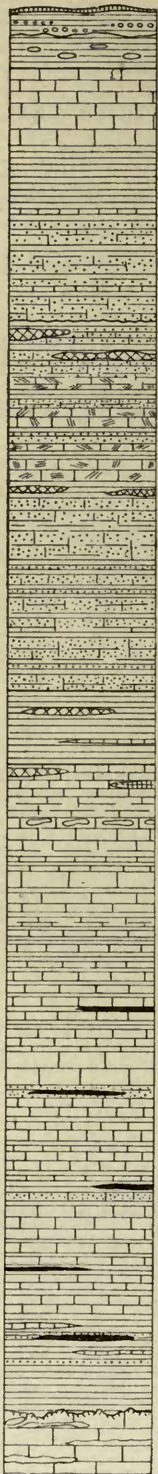
FORMATIONS OF SOUTHERN ILLINOIS.

(After S. Weller, T. E. Savage, and others, 1905—1910).

Per.	Div.	Formation.	Strata.	M.	Description.
Silurian.	Lower-Middle.	Niagara.		45 +	Light buff to gray dolomite. (*Pentamerus oblongus, Syringopora tenella*, etc.).
Ordovician.	Upper.	Maquoketa.		50—70	Gray argillaceous and calcareous shale, locally fossiliferous, and magnesian at the top. (*Orthoceras sociale*). Plastic blue and green shale and clay with indurated fossiliferous bands near the top. Drab and blue, thin, fissil shale and fossiliferous, thin, argillaceous limestone (*Ctenodonta fecunda, Liospira micula*, etc.). Fine conglomerate locally near base.
		Unconformity. (?)			
	Middle.	Galena.		72	Coarse-grained gray dolomite, with thin, shaly fine-grained limestone and locally carbonaceous shale at base. (*Receptaculites oweni, Orthis tricenaria, Strophomena incurvata, Ceraurus pleurexanthemus*, etc.).
		Platteville. (Trenton).		17	Fine-grained limestone and very fossiliferous, calcareous shale (*Orthis subaequata, Streptelasma profundum, Thaleops ovata*, and bryozoans). Thick-bedded magnesian limestone with thin, sandy shale at base.
		St. Peter.		10—55	White or iron-stained quartz sandstone, massiv and usually poorly cemented. Thin, sandy clay-shale at base.
		Unconformity.			
	Lower.	Prairie-du-Chien. (Lower Magnesian).		30 +	Irregularly bedded, rough-weathering dolomite, cherty in places and locally containing thin beds and lenses of sandstone. Fossils rare.

FORMATIONS IN SOUTHWESTERN WISCONSIN.[1]

[1] After U. S. Grant, U. S. Geol. Survey, 1907.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.		"Plains marl."		0—3	Gray, calcareous earth and marl. *(Elephas primigenius).*
		— Unconformity. —			
Miocene.	Upper.	Ogalalla.		30 ±	Loam, clay and calcareous gravel beds. *(Protohippus, Aphelops, Procamelus* and *Trilophodon).*
		Unconformity.			
Upper Cretaceous.	Montana.	Fort Pierre.		45 +	Shale, containing large fossiliferous concretions. *(Avicula fibrosa, Baculites ovatus).*
	Colorado.	Niobrara.		114 ±	Chalk; firm, buff, blue or pink. *(Haploscapha grandis, Ostrea congesta, Mosasaurus proriger, Xiphactinus audax, Hesperornis regalis).*
		Benton.		105	Blue shale and thin limestone below, variegated and dark blue shale above. *(Inoceramus labiatus, Prionotropis woolgari, Ostrea lugubris).*
Lower Cretaceous. (Comanchean).	Washita.	Dakota.		75	Variously colored shale, with coarse brown sandstone. *(Sassafras cretaceum, Ficus incqualis, Hedera ovalis, Juglans crassipes).*
		Mentor.		18 ±	Marine and freshwater shale and sandstone, white to dark brown in color. *(Sassafras cretaceum, Salix protæafolia, Cardium kansasense, Turritella belviderei, Unio belliplicata?).*
		Belvidere.			
		— Unconformity ? —			
Permian.	Upper.	Greer.		50 ±	Coarse yellow to brown sandstone and blue to black shale with thin limestone above. *(Rus uddeni, Gryphæa navia, Trigonia emoryi).*
				84 ±	Beds of massiv gypsum, red clay, shale and sandstone. *(Schizodus sp.,* and ammonoids).
		Woodward.		145 ±	Dolomite, red sandstone and shale. *(Cyrtodontarca? gouldii, Dielasma schucherti, Trepospira haworthi).*
				23 ±	Beds of massiv gypsum, red clay and shale and some dolomite. *(Schizodus, Pleurophorus).*
		Blaine.			
		Salt Fork.		275 +	Red sandstone and saliferous shale.
	Lower.	Wellington.		60—140	Bluish-gray to slate-colored and even red shale. Occasional beds of impure limestone and gypsum. Fossils scarce. *(Eoblattina curta, E. permiana, E. pecta, Puknoblattina curvata, Estheria minuta).*
		Marion.		45 +	Soft buff limestone and marl with some beds of gypsum and salt. *(Eumicrotus hawni, "Bakewellia" parva, Pleurophorus subcuneatus).*
Permo-Carboniferous.		Chase.		85 ±	Buff, massiv limestone, chert, shale and marl. *(Pleurophorus subcuneatus, "Bakewellia" parva, Myalina permiana).*
		Council Grove.		45 ±	Gray limestone overlain by limestone alternating with shale. Locally gypsum. *(Thamniscus octonarius, Fusulina, Strophalosia, Derbya multistriata).*
		McFarland.		55—60	Shale and alternating limestone below, overlain by bluish limestone, with variegated shale at top. *(Meekopora prosseri, Nodosaria postcarbonica).*
		Wabaunsee (emended).			
Pennsylvanian.		Stage G.		75 ±	Limestone, alternating with blue to yellowish clay shale. Thin beds of coal. *(Fusulina secalica, Enteletes hemiplicata, Allorisma terminale).*
				100 ±	Blue limestone with thin beds of shale, and coal. *(Streblotrypa prisca, Fusulina secalica, Echinocrinus aculeatus, Fenestella hexagonalis, Productus cora, Pugnax utah,* etc.).
		Stage F.		170 ±	Gray limestone, crystalline, oolitic and locally cherty. Bituminous shale with some sandstone and thin beds of coal. *(Steinmannia benjamini, Enteletes hemiplicata, Limoptera longispina, Spiloblattina maledicta).*
		Stage E.		35 ±	Shale with local beds of coal and sandstone. Limestone at the top. *(Phialocrinus magnificus, Spiriferina kentuckiensis, Campophyllum torquium).*
		Stage D. Drum.		9 ±	Pure limestone, locally oolitic. *(Eumicrotus equistriatus, Cypricardinia carbonaria).*
		Stage C.		60 ±	Pure limestone separated by clay shales. *(Chonetes verneuilianus, Acanthopecten carboniferus, Tegulifera kansasensis, Lophophyllum westii,* etc.).
		Stage B. Marmaton.		105 ±	Limestone, thin bedded to massiv, separated by shales. Some beds of coal. *(Chaetetes milleporaceus, Chonetes mesolobus, Squamularia perplexa).*
		Stage A. Cherokee.		140 ±	Argillaceous, arenaceous and bituminous shale containing calcareous lentils, coal and considerable sandstone. Oil and natural gas. *(Marginifera muricata, Chonetes mesolobus, Asymptoceras newloni, Domatoceras umbilicatum, Temnocheilus crassus, T. depressus,* etc.).
		— Unconformity. —			
Mississippian.	Lower.	Boone.		85—130 +	Limestone and dolomite with interbedded chert. *(Cyclopora fungia, Spirifer keokuk, Productus laevicosta, Dielasma gorbyi, Syringothyris texta,* etc.).

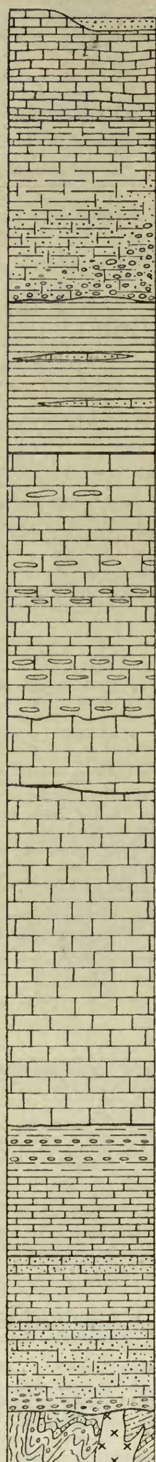
FORMATIONS IN KANSAS.[1]

[1] By C. S. Prosser and J. W. Beede, 1911. Post-Cretaceous compiled by E. Blackwelder.

Per.	Div.	Formation.	Strata.	M.	Description.
Oligocene.	Lower.	White River.		30—60	Buff, sandy clay with basal conglomerate (*Oreodon Culbertsoni, Titanotherium*, etc.).
		Angular unconf. —			
Cretaceous (Upper).	Upper.	Laramie (?). (Part Paleocene?)		760	Massiv yellow and gray sandstone and shale, with lignite.
		Fox Hills.		76	Buff and gray sandstone and shale.
	Middle.	Pierre.		365-425	Dark-gray shale with limestone lenses (*Nautilus dekayi, Baculites compressus*, etc.).
		Niobrara.		36—69	Buff impure chalk and calcareous shale (*Ostrea congesta*).
		Benton. Carlile.		180—240	Gray to black shale with thin sandstones and concretions (*Prionocyclus woolgari*).
		Benton. Greenhorn.		15—24	Impure dark slabby limestone (*Inoceramus labiatus*).
		Benton. Graneros.		275—350	Dark shale with local sandstone in lower part.
Comanchean (Lower Cretaceous).	Lower.	Dakota.		3—49	Gray to buff sandstone, mostly massiv (leaves of dicotyls).
		Fuson.		3—50	Shale, mostly massiv, white to purple, withsandstone layers (cycads).
		Lakota.		8—90	Buff sandstone, mostly hard, coarse, cross-bedded (*Estheria, Lepidosteus*, cycads, etc.).
Com'n or Jura.		Morrison.		12—67	Massiv shale, gray, greenish, and maroon, with thin limestone (*Ceratosaurus, Stegosaurus, Atlantosaurus*, etc.).
Jurassic.	Upper.	Unkpapa.		1—46	Massiv fine-grained sandstone, white, buff, purple.
		Sundance.		60—107	Gray shales, buff soft sandstone, reddish sandy shale (*Camptonectes bellistriata, Pseudomonotis curta, Belemnites densus*, etc.).
		— Unconformity (?) —			
Triassic (?).		Spearfish.		138—212	Red sandy shale with gypsum beds (no fossils).
Permian (?).		Minnekahta.		8—14	Thin-bedded gray limestone (*Bakewellia ?, Edmondia ?*, etc.).
		Opeche.		18—30	Red slabby sandstone and sandy shale (no fossils).
Pennsylvanian.		Minnelusa.		110—185	Sandstone, mainly white, buff, or red, with thin beds of limestone.
Mississippian.	Lower.	Pahasapa.		30—215	Massiv gray limestone (*Chonetes loganensis, Spirifer centronatus*, etc.).
		Englewood.		8—20	Pink to buff slabby limestone (*Spirifer peculiaris, Schuchertella crenistriata*).
Ordovician.	Lower.	— Unconformity. (?)			
		Whitewood.		0—30	Massiv buff limestone, mottled with brown. (*Maclurina, Endoceras annulatum, Dalmanella testudinaria*, etc.).
Cambrian.	Middle-Upper.	Deadwood.		60—150	Brown sandstone, partly conglomeratic, mostly massiv; greenish gray sandy shales, slabby dolomitic limestone, and limestone conglomerate (Fossils in lower beds: *Dicellomus politus, Ptychoparia oweni, Olenoides*, etc.).
		Angular unconf. —			
Algonkian.		Schistose series.		?	Micaceous, graphitic, and hornblendic schists, with quartzite and conglomerate; granitic intrusives.

GENERALIZED SECTION OF THE NORTHERN BLACK HILLS, SOUTH DAKOTA.[1]

[1] Modified after N. H. Darton, U. S. Geol. Survey, 1909.

Per.	Div.	Formation.	Strata.	M.	Description.
Pleistocene.		— Unconformity. —		0—10	Sand in small streams. Fine silt in Llano and Colorado rivers.
Comanchean (Lower Cretaceous).		Edwards.		0—45	Massiv, well bedded white limestone.
		Comanche Peak (including Walnut).		15—18	White chalky limestone. Locally has clay-like bed at base.
		Trinity.		0—150	Conglomerate and sandstone in basal portion, merging horizontally into white and yellowish banded limestones of various thicknesses, flaggy and marly in places. Contains also clay-like beds.
		Angular unconf. —			
Pennsylvanian.		Smithwick.		9—120	Very dark carbonaceous shale, containing thin sandstone lentils. Weathers yellowish brown.
		Marble Falls.		75—140	Dove-colored gray to dark blue or black limestone, locally carrying considerable dark or black chert.
		— Unconformity. —			
Cambro-Ordovician.		Ellenburger.		40—300	Limestone and dolomite, white and grayish tones. Locally carries great abundance of chert. Bedding usually ill-defined. A local unconformity in the upper part.
		— Unconformity? —			
Cambrian.	Upper.	Wilbern's.		45—68	Limestone and calcareous shale. Shale largely in upper third where flat shale pebble conglomerates and rounded shale pebble conglomerates are characteristic. Lower portion is often mottled, flaggy and well bedded and carries disseminated glauconite grains.
		Cap Mountain.		27 ±	Formation capped by 3 to 15 meters glauconitic calcareous and siliceous sandstone. Lower portion flaggy, mottled limestone, of gray color, with some glauconite.
		Hickory.		0—75	Conglomerate at base passing to sandstone and finally grading into limestones at top. Sandstone, various tones of red, gray, brown, and white. Conglomerate locally 25 meters thick.
		— Unconformity. —			
Algonkian?		Llano. Packsaddle schist. Valley Spring gneiss.		?	Mica, hornblende, graphite, and quartzite schists, limestone bands, and gneisses, granite intrusives, amphibolite, dioritic, and gabbroic rocks, etc.

GENERALIZED SECTION IN THE LLANO, TEXAS, REGION.[1]

[1] After S. Paige, U. S. Geol. Survey, 1911.

thruout the district by its distinctiv fauna. The third (Niagara) limestone is thicker in the west than in the east, where it is partly replaced by shale and sandstone. A middle Devonian limestone formerly called the "Corniferous" prevails in the northeastern part of the region, but is not generally recognized west of the Mississippi River. The fifth important limestone is found in the Mississippian system and is best known along the central course of the river of that name; it gradually disappears eastward. These formations are generally separated from each other by shales, and eastward the shales increase in prominence or pass into sandstones.

Altho nearly all of the beds lie flat, there are obscure unconformities here and there at several horizons. Some of these are local in their distribution, but at least three are widespread and important. The first of these interruptions is at the top of the Cambro-Ordovician limestone and has been recognized almost thruout the Interior Lowlands. The second is late Ordovician and lies at the base of the widespread shale which carries the Richmond fauna. This has been found at widely scattered localities but is generally so obscure as to escape detection. Another interruption in the lower part of the Devonian system has broad extension. Thruout much of the region the middle or upper Devonian rocks rest upon the Niagara limestone and in some places upon older formations.

The faunas of these strata are in part provincial, but at least three great cosmopolitan faunas are recognizable. The oldest of these is middle or upper Ordovician and is especially characteristic of the Trenton limestone. The second, found in the Niagara limestone, is Silurian and has many species in common with Europe and Asia. The last is the great holarctic fauna of the upper Devonian, which continued with modifications into the Mississippian.

Upon this sequence of earlier Paleozoic strata rest the upper Carboniferous and later formations. The Pennsylvanian coal measures are separated from the underlying rocks almost everywhere by an erosional unconformity, and in consequence of mild deformation following the Mississippian period this unconformity is more conspicuous than any other within the Paleozoic group. The Pennsylvanian system in this region consists largely of shales with alternate sandstones and limestones and occasional coal seams. The basal beds are generally sandstone with more or less conglomerate and only occasional thin coal seams. This formation was formerly called the Millstone grit, but it is now given various local names such as Pottsville or Mansfield sandstone. In the western part of the region the limestones are more numerous, while eastward the sandstones and coal beds increase in number and thickness. Over broad areas of the interior Lowlands the Pennsylvanian is the latest formation and hence is widely exposed at the surface.

Along the eastern border of the region an upward continuation of the Coal Measures contains fossil plants of Permian age. In the Great Plains of the West the youngest Paleozoic formations are generally red earthy sandstones and shales with occasional beds of gypsum; they pass gradually up into the Triassic. In Kansas and neighboring states the upper part of the Carboniferous system beneath the Red Beds contains marine fossils. By many these are considered Permian, while others regard them as merely late Pennsylvanian.

Mesozoic. The Mesozoic rocks are confined to the western part of the Interior Lowlands. On the western border the Triassic is poorly represented by red shaly sandstone and gypsum, usually not distinguishable from the similar Permian deposits. Marine Jurassic beds lie upon the red beds on the extreme northwest edge of the region.

The chief Mesozoic rocks of the western interior are the Cretaceous beds. The Lower Cretaceous (Comanchean) strata are best developt in the southwest, — in Texas and Oklahoma. They consist of weak sandstones, shale, and chalk, in part almost un-

cemented. The limestone becomes thicker southward and is not present in the northern part of the district. Upon the Lower Cretaceous the Upper Cretaceous rests in some places conformably and in others unconformably. At its base there is the widespread but thin Dakota sandstone which is particularly important as a reservoir of artesian water in the semi-arid plains. This contains locally an abundance of fossil leaves and is apparently not marine. The Dakota sandstone is followed by a thick succession of shales or clays with a prominent chalk formation (Niobrara) near the middle and an increasing proportion of sandy beds toward the top. The whole succession is divided into several formations which are recognized by their fossils.

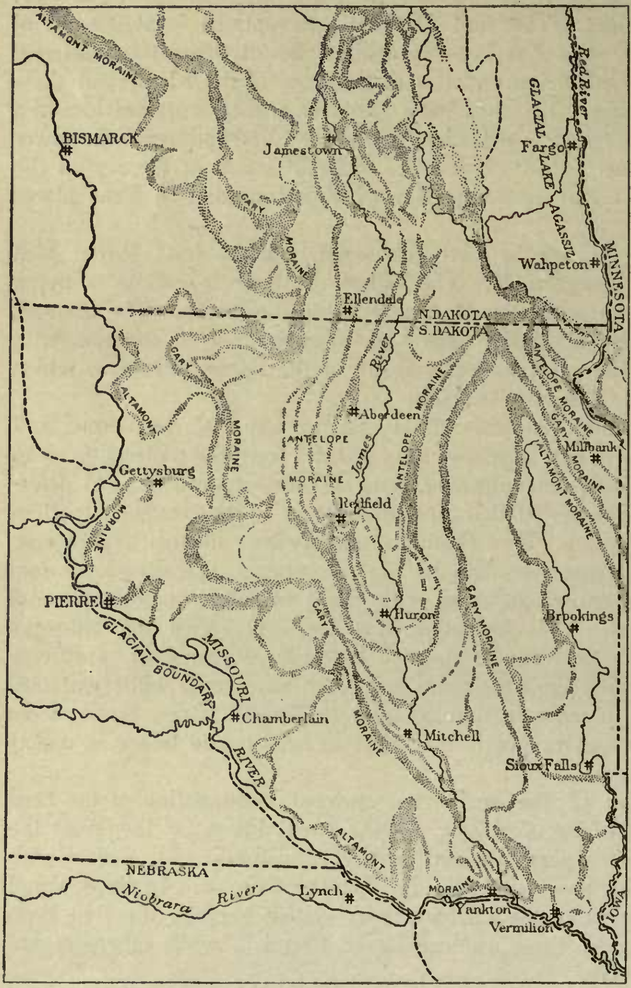


Fig. 23. Distribution of glacial moraines in eastern North and South Dakota, showing the lobate form of the retreating ice edge. (After Todd and others, U. S. Geol. Surv.)

T e r t i a r y C o n t i n e n t a l D e p o s i t s. Tertiary formations cover the Mesozoic terranes extensivly in the western part of the district, but are generally absent east of the Missouri River. In the Great Plains the Tertiary sediments comprise unconsolidated gravel, sand, and clay, which in that dry climate have been eroded into the picturesque hills known as the Bad Lands. The Tertiary sediments are nearly everywhere separated from the underlying Cretaceous by an unconformity, but as all of the beds are nearly horizontal, it is not conspicuous. A varied series of vertebrate fossils has been obtained from the Tertiary beds of the plains. These are chiefly of Oligocene and Miocene ages, but the Pliocene and early Pleistocene are represented.

G l a c i a l D r i f t. A broad sheet of Quaternary glacial drift covers the northern part of the Interior Lowlands and extends southward almost to the junction of the Ohio and Mississippi Rivers. Chamberlin and others have shown that this sheet of drift is composite, consisting of successiv layers of different ages, separated by old soil zones and even beds of interglacial alluvium. There is difference of opinion as to just how many sheets of drift can be differentiated, but four or five have been generally accepted. The till is arranged partly in the form of definit moraines, drumlins, and

other special glacial features, and partly in the form of irregular undulating sheets. Connected with the till are extensiv deposits of glacio-fluvial sands and loams. Along the larger rivers they now form prominent terrace deposits.

The following stages of the glacial period are recognized in the interior of North America by CHAMBERLIN[1]:

XIII. The Champlain sub-stage (marine).
XII. The glacio-lacustrine sub-stage.
XI. The Later Wisconsin, the sixth advance.
X. The fifth interval of deglaciation (as yet unnamed).
IX. The Earlier Wisconsin, the fifth invasion.
VIII. The Peorian, the fourth interglacial interval.
VII. The Iowan, the fourth invasion.
VI. The Sangamon, the third interglacial interval.
V. The Illinoisan, the third invasion.
IV. The Yarmouth, or Buchanan, the second interglacial interval.
III. The Kansan, or second invasion now recognized
II. The Aftonian, the first known interglacial interval.
I. The Nebraskan, the earliest known invasion.

Outside of the glaciated area and away from the stream courses there are deposits of loess and other loams and sands, partly wind blown, and perhaps partly of fluvial origin. The *Equus* beds of Kansas and other formations in this group have yielded bones of early Quaternary mammals, including horses, elephants, camels, gigantic edentates, bison, and many other forms.

Along the streams recent alluvial matter has accumulated in relativly small quantities. The region is at present undergoing erosion rather than sedimentation.

Structure.

General. The pre-Cambrian rocks are folded and more or less metamorphosed. Some of them are intruded by a variety of igneous rocks. They are almost everywhere buried by younger strata.

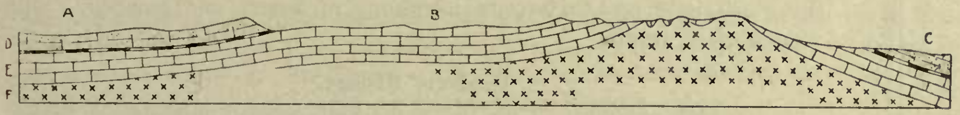


Fig. 24. Profile of the Ozark uplift in Missouri: A, Joplin; B, Ozark plateau; C, Mississippi River; D, Carboniferous shale and sandstone; E, Paleozoic limestone and sandstone; F, pre-Cambrian granitic rocks. (After W. S. T. SMITH and C. E. SIEBENTHAL, U. S. Geol. Surv.)

The Paleozoic and Mesozoic rocks which underlie most of the Interior Lowlands element are generally undisturbed. They are, however, gently undulating, having been bulged into low domes such as that of the Ozark region in Missouri or deprest into shallow synclines like that of Michigan. Exceptionally there are sharper folds of relatively small displacement, and in some districts normal faulting has made important changes in distribution. For example, in northern Illinois a sharp unsymmetrical anticline trending south by east brings Ordovician rocks up from beneath Carboniferous; and along the Ohio river in western Kentucky the Paleozoic rocks are broken by many normal faults. Volcanic intrusions are rare thruout the interior region. A few small dikes cut the Paleozoic rocks in central New York and near the mouth of the Ohio River; and in southwestern Texas post-Cretaceous igneous rocks are some-

[1] CHAMBERLIN, T. C., and SALISBURY, R. D., Geology, Vol. III, 1906, p. 383.

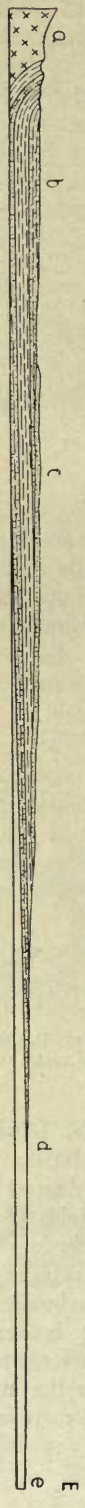


Fig. 25. Profile of the Great Plains, largely in Nebraska, from the Laramie Mountains of Wyoming to the Missouri River: a, Laramie Mts. 2500 m. above sea level; b, Cretaceous sediments; c, Tertiary clay and sand; d, base of Cretaceous system; e, Missouri River in Paleozoic strata at 250 m.

what more common. The last may be considered as transitional to the volcanic province of the Rocky Mountains and western plateaus.

The Cenozoic deposits are essentially undisturbed and the sediments largely unconsolidated. They are associated with no volcanic rocks, altho in the Great Plains there are beds of volcanic ash, probably blown scores of miles from Tertiary volcanos in the Rocky Mountains.

Distribution of Structures. In the eastern part of the Interior Lowlands the Paleozoic rocks have been gently warpt into broad basins and domes. The Cincinnati and Nashville domes bring up Ordovician rocks, surrounded by the later Paleozoic outcrops. The Wisconsin shield and Adirondack dome may be of similar origin, since the Paleozoic beds dip gently away from the outcrops of the pre-Cambrian rocks. In all of these structures the dips are low (generally less than 1 degree) and there are but few noteworthy faults.

In the Ozark region of southern Missouri and northern Arkansas the Paleozoic beds form a low flat dome, in the center of which Cambrian and pre-Cambrian rocks are exposed. Around the periphery of the dome tension faults are not uncommon, and on the eastern border small faults are in some places numerous.

In central Texas the Llano inlier of ancient rocks is reported by Paige to be a round horst with peripheral faults and gentle folds in the Paleozoic rocks. The downthrown sides of the faults now stand topographically higher because the soft pre-Cambrian rocks are less resistant to erosion than the Paleozoic beds.

In the Great Plains the structure is that of a very broad syncline with almost imperceptible dips on the east side, but with a more abrupt flexure on the west at the edge of the Rocky Mountains. This great geosyncline is filled with Mesozoic as well as Paleozoic sediments.

In the extreme southwestern corner of the region, where it grades into the block plateaus and mountains of southwestern Texas, the rocks are considerably broken by intersecting normal faults. Associated with these are local post-Cretaceous intrusions of basalt and monzonite with some surface eruptivs.

Geologic History.

Pre-Cambrian. Long before the beginning of the Cambrian period, the older rocks were folded and intruded by igneous rocks. Ever since then the Interior Lowlands region has been comparativly quiet tectonically.

The Paleozoic Epicontinental Sea. During most of the Paleozoic periods the interior of the United States was more or less completely submerged by a shallow sea. From time to time there were important oscillations of the shoreline, and different kinds of sediments were deposited here and there. Almost all of the region was submerged in middle Ordovician time and again in the middle of the Silurian period. On the other hand there was general emergence early in the Ordovician and again late in the same period. In late Silurian time the land appears to have been even more extensiv, and there is clear evidence of an arid climate in the northeastern part of the province. There was a fourth general emergence in the middle of the Carboniferous. The late Ordovician expansion of the land probably coincided with the intense folding in the New England-Piedmont region, and it seems to have been accompanied by very gentle warping in the northeastern states, giving form to such features as

the Cincinnati arch. Similar mild deformation accompanied the emergence at the end of the Mississippian period, and made low folds chiefly in the Mississippi valley.

P e r i o d s o f E x p a n d e d L a n d. From the close of the Mississippian until the Cretaceous, the Interior Lowlands were more generally above sea-level than below. During the Pennsylvanian period the emergent tendency may be traced in the coal measures of the eastern states, indicating, as they do, oscillations very close to sea-level. In the West the epicontinental sea lingered on into the Permian, but even there it disappeared before the end of the Paleozoic era.

Of Triassic and Jurassic times the Interior Lowlands province affords scant record. Probably the entire region was land, and there is evidence that at least the western part was subject to an arid climate, which made its appearance as early as the end of the Pennsylvanian period.

I n u n d a t i o n s o f t h e G r e a t P l a i n s. In later Mesozoic times the western part of the interior Lowlands as well as the adjacent Rocky Mountains constituted a part of a very broad and relativly shallow depression. This was invaded first from the North by an arm of the Arctic Ocean late in the Jurassic period, but the inundation was brief. In the succeeding Comanchean period, the sea came in from the southwest at least as far as Kansas, but was again excluded. The climax of inundation was reached in the Cretaceous (Senonian) period when the sea completely submerged the Great Plains region and extended eastward at least as far as the Mississippi River in Minnesota. Meanwhile, the eastern states seem to have been progressivly eroded to a peneplain,—a fact implying unusual freedom from warping and other deformativ movements. The climate thruout the region was evidently moist and mild.

D i s t u r b a n c e s a t t h e C l o s e o f t h e C r e t a c e o u s. At this time the deformation of a part of the great Mesozoic depression of the West produced the Rocky Mountains and fixt the boundary of the Interior Lowlands region more definitly. Altho the folding did not extend east of the Rocky Mountains, there was general emergence of the plains at this time, followed by erosion. The denudation seems to have been most effectiv in the east and northeast. In the Ozark region there are faults and small intrusions of ultra-basic igneous rocks which apparently date from this time. Other local faults and intrusions were made in western Texas.

T h e C e n o z o i c L a n d E r a. During the Tertiary period the eastern portion of the region seems to have been continuously subject to erosion. In the Great Plains, however, considerable local deposits were made. The Great Plains seem to have been much lower in the Eocene than now, but to have assumed more nearly their present topography and climate in Miocene and Pliocene times.

During the Quaternary period a succession of great ice sheets slowly advanced from the north and spread southward over the northern states, extending at one time almost to the mouth of the Ohio River. The glacial invasions were separated by relativly long interglacial epochs during some of which the climate must have been as mild as in the Tertiary period preceding. During these times representativs of the old Pliocene fauna re-entered the glaciated region. Before the close of the Quaternary, however, many of the larger Tertiary mammals had become extinct. There is no evidence that the human species arrived in the United States until that time.

The Interior Lowland has been subject to gentle warping since the last ice sheets disappeared. On the whole there seems to have been a rather general elevation of the region particularly in the east and west since Pliocene time.

Physiography.

T o p o g r a p h y. In so large a region as the Interior Lowlands element, there is necessarily much diversity of surface. Along the southeastern border and again in the Ozark region of the central states, plateaus have been deeply dissected by valley

systems, so that the surface is now hilly or even mountainous. In the West still higher plains are not yet much dissected. They constitute a plateau with a gentle eastward slope toward the Mississippi valley. In Texas the southward continuation of the Great Plains, known as the "Staked Plains", drop off rather sharply to the Gulf coastal plain along a faulted zone.

Between these two elevated areas lies the broad shallow trough occupied by the Mississippi River. The surface there is generally hilly, with a relief of 10 to 50 meters. The larger valleys have flat bottoms of moderate width, and between them there still remain considerable areas of undissected upland in the form of flat ridges. Portions of the northern states from North Dakota on the west to New York on the east have topography entirely of glacial origin. The surface is covered with moraines, outwash plains, scattered lakes and the flats representing extinct lakes. The drainage is characteristically aimless and disorderly.

Physiographic History. Of the pre-Cretaceous topography of the Interior Lowlands probably little or nothing now remains. On the eastern border of the province the tops of the highest plateaus and mountains seem to correspond with the Schooley peneplain of the Appalachian region, but this has not yet been traced far westward, altho it seems to be identifiable in the Ouachita element on the south.

It is probable that the old surface represented by the tops of the flat ridges in the central and western states is not older than late Tertiary. In the Great Plains it is evident that this surface cannot be older than Miocene, since the uplands are largely capt with Miocene deposits. Altho the existing drainage may well have been blockt out in a general way in the Tertiary period, there is much reason to believe that the present valleys have been excavated almost entirely within the Quaternary. Most of the valley systems are distinctly young, as indicated by the fact that their tributaries do not extend far back into the plateaus. In the north-central states, furthermore, the Kansan and Illinoisan drift sheets of early Quaternary age are now well dissected by ramifying valley systems.

Within the glaciated region the previous topography was almost wholly obliterated by the deposition of drift. An area in southwestern Wisconsin was surrounded by the ice sheets, but not covered by them, and hence preserves an example of the erosional topography of the district invaded by the glaciers. Since the older sheets of drift were deposited, erosion has workt out a complex system of valleys in such states as Iowa and Illinois. Only the larger streams, however, have thus far developt broad flat bottoms. In the area covered by the latest ice sheet there has been scarcely any modification of the glacial topography. The rivers have terraced the outwash deposits in their valleys, but the majority of the glacial features remain unchanged.

In that portion of the Great Plains not affected by the ice sheet there is evidence of important changes in physiographic activities. Valleys of rivers like the Platte and the Arkansas were once considerably deeper than now, but are being filled with deposits of sand and gravel washt down from the Rocky Mountains. It is believed that the deepening was accomplisht by the rivers during one of the glacial epochs when the climate was cooler and more moist, and that the valleys are being filled under the influence of the warmer drier climate of today.

Seismicity.

In general the Interior Lowland is a region of tectonic quiet. In the two or three centuries during which the region has been fairly well known, only one strong earthquake has occurred. This disturbance, known as the New Madrid earthquake, was really a series of shocks felt in the years 1811—12. The more violent of these were felt over a radius of 700 to 1000 miles, and near the center of the disturbance (Western Tennessee) the shocks were destructiv. At the time of this disturbance con-

siderable areas along the Mississippi River subsided and are now occupied by swamps or lakes. The cause of the New Madrid earthquake is not known.

Mild shocks have been felt elsewhere in the Mississippi valley at infrequent intervals. None of these would be considered worthy of mention in a region subject to earthquakes.

Atlantic and Gulf Coastal Plain.

General.

The Coastal Plain borders the Atlantic and Gulf shores of the United States from southern New England around into Mexico. Florida is but a seaward extension of it, and along the Mississippi river the plain stretches northward as a deep embayment. On the Atlantic side the Coastal Plain is distinctly separated from the adjoining low Piedmont Plateau by the so-called "fall line":— where the rivers descend from the harder crystalline rocks into the weak sediments of the Coastal Plain, they are markt by rapids which constitute barriers to navigation. The position of this line has determined the location of many important cities, such as Philadelphia. Farther west in Texas the Coastal Plain is markt off from the low plateaus of the Great Plains by a zone of faulting along which the Cretaceous beds on the southeast have subsided relativly. The seaward margins of the coastal plains are partly submerged; a relief model of the United States shows the broad continental shelf bordering the shore.

Altho the topography of the Coastal Plain presents little relief it is by no means uniform. Inland, along the edges of the higher lands, it is dissected by ramifying valleys which have left it a region of low hills. Along the present shore line the ends of the valleys are drowned, making deep embayments skirted by wide marshes. These two contrasted portions intergrade.

Because the Coastal Plain is composed of various sediments its soils are not everywhere the same. Along certain belts parallel to the coast there are sandy soils, and especially where these are associated with hilly topography, the land is but little cultivated and is clad with forests, largely of pine. Along the coastal swamps of the South dense growths of cypress and mangrove are helping to build out the shore with peaty deposits. In the fertil lowlands, especially along the outcrops of chalky strata, great crops of cotton, sugar and other staple products have been raised for many generations.

In general the Coastal Plain is composed of post-Jurassic rocks which are essentially undeformed and dip very gently seaward. Most of the strata are unconsolidated, but locally they have been cemented to firm rocks. The plain consists of a series of thin but very widespread strata, the base resting with markt unconformity upon Triassic or older rocks. Only on the northwestern side of the Gulf Plain of Texas is this unconformity inconspicuous.

Stratigraphy.

In the Coastal Plain there is a sequence of strata ranging from the close of the Jurassic to the present. This sequence is nearly complete, but is interrupted by many unconformities representing brief time intervals. The beds are partly marine and partly terrestrial, and the individual formations vary from place to place.

At the base of the coastal series lie sediments which are possibly late Jurassic but more probably Comanchean (Lower Cretaceous) in age. East of the Mississippi River these beds are wholly non-marine, consisting of alternating clays, sands and gravels of gray, green, and yellow colors. They contain fossil plants, *Unio* and dinosaurs, and are interrupted by local unconformities. West of the Mississippi River the Comanche series consists largely of marine shales and chalk, but there are terrestrial beds at the base. The thickness of the Comanchean system varies from about 200 meters in New Jersey to more than 1200 in Texas.

On the eroded surface of the Comanchean system rest Cretaceous beds about equally extensiv but largely composed of marine deposits. In the East greensand and clay are prominent, while along the Gulf coast and especially in Texas there is much

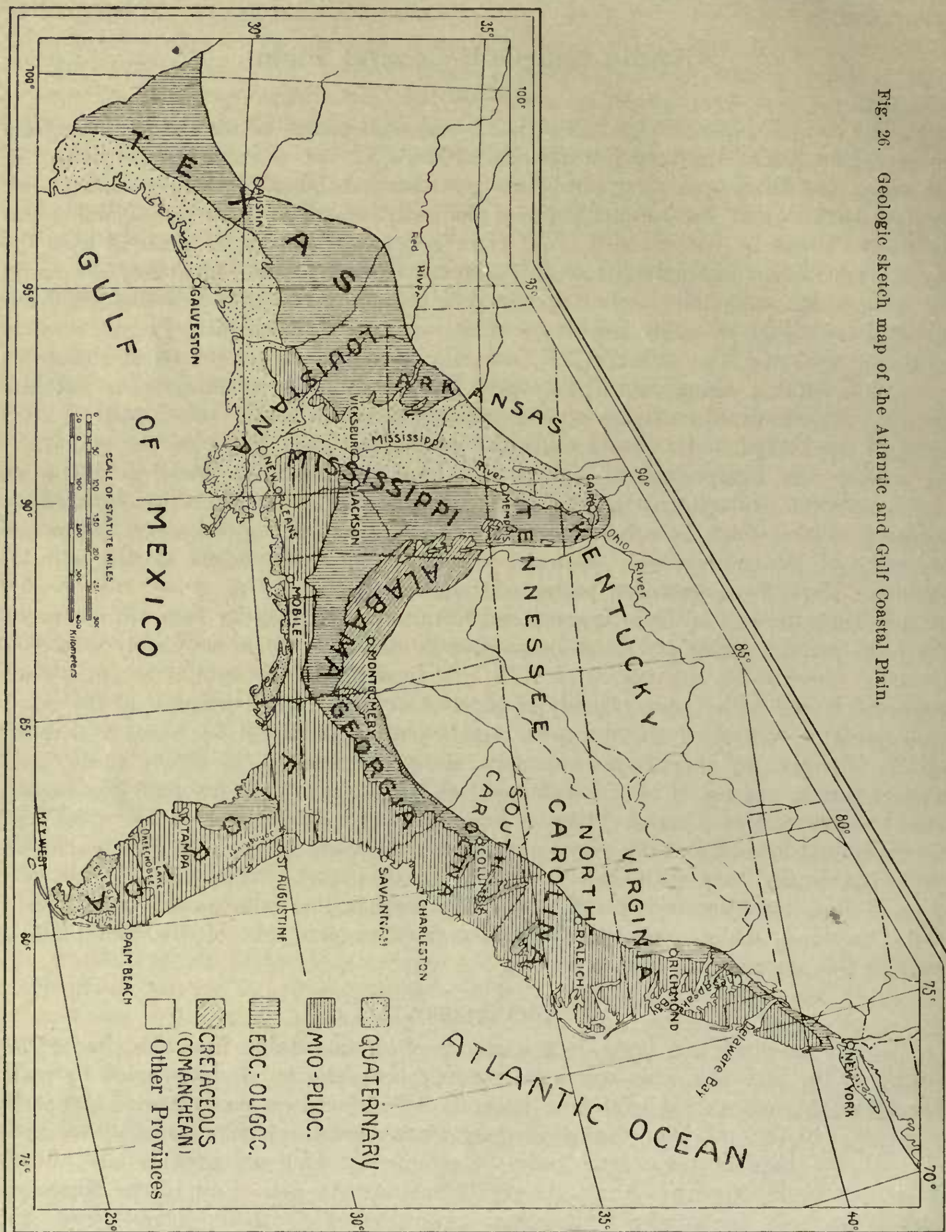
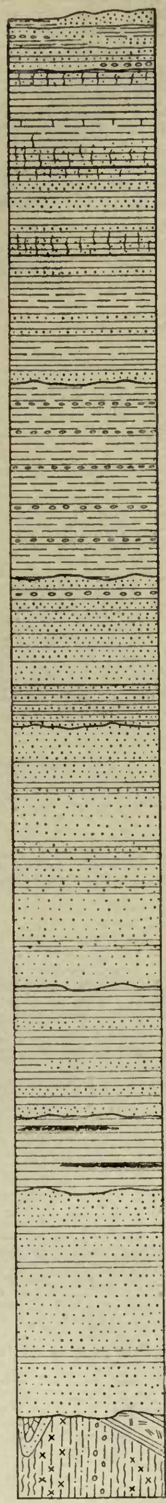


Fig. 26. Geologic sketch map of the Atlantic and Gulf Coastal Plain.

chalk. The early Tertiary rocks, representing both Eocene and Oligocene periods, rest with obscure unconformity upon the Cretaceous and in many respects are like the subjacent formations. Near the Mississippi embayment the lowest beds are fluviatile and contain thin lenses of lignite. On the average there is less chalk in the Eocene than

Per.	Div.		Formation.	M.	Description.
Quaternary.	Recent.		Columbia.		Allnvium, terrace deposits and wind-blown sand.
	Pleistocene.			10+	Terrace deposits of gravel, sand and clay containing both marine and land fossils.
	Pliocene.		Lafayette.	10+	Terrace deposits of clay, loam, sand and gravel.
			Unconformity.		
Tertiary.	Miocene.	Chesapeake.	St. Marys.	45	Sandy clay with pnre clay and marl. (*Pecten Jeffersonius, Cardium laqueatum*, etc.).
			Choptank.	40	Yellowish sandy clay and sand. (*Turritella plebeia, Venus mercenaria*, etc.).
			Calvert.	60	Clay, sand, marl and diatom earth. (*Corbula elevata, Phacoides contracta*, etc.).
			Unconformity.		
	Eocene.	Pamunkey.	Nanjemoy. Aqnia.	90	Greensand and marl (*Crassatellites alaeformis, Venericardia potapocoensis, Corbula oniscus*, etc.).
			Unconformity.		
Cretaceous.	Upper.		Rancocas.	20±	Sand and greensand with marine fossils.
			Monmouth.	30±	Red and pink sands with greensand.
			Matawan.	3	Dark colored sandy clay with marine fossils. (Senonian).
			Magothy.	6—27	Laminated sand and clay containing land plants of Cenomanian age.
			Unconformity.		
			Raritan.[1]	120±	Sand and sandy clay containing plant remains (many dicotyledons).
			Unconformity.		
	Lower (or Comanchean).		Patapsco.	60	Bright colored variegated clay and interbedded sandstone, with land plants.
			Unconformity.		
			Arundel.	35	Dark lignitic clays with lenses of carbonate iron ore; fossil plants and dinosaurs.
			Unconformity.		
			Patuxent.	105 +	Sandy clay and sands, chiefly arkosic, with fossil ferns, cycads and conifers.
			Unconformity.		
Triassic and Older Rocks.					Folded, faulted and in part metamorphosed.

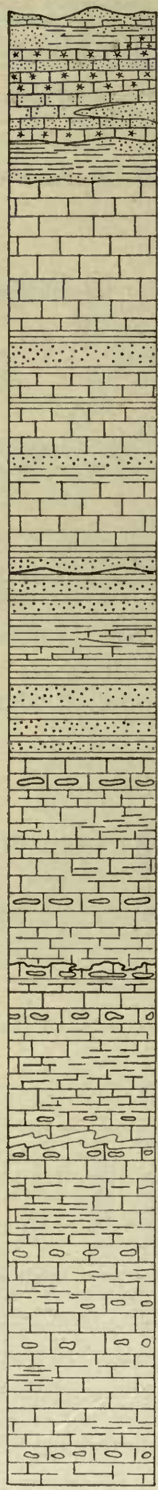
Strata.



FORMATIONS OF EASTERN MARYLAND.[2]

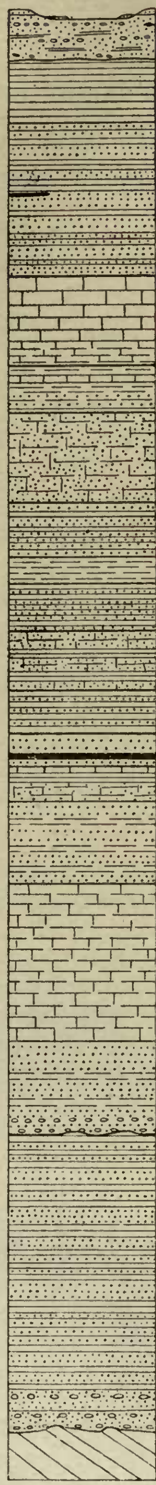
[1] According to recent studies by E. W. Berry, the flora of the Raritan formation indicates clearly that it is of early upper Cretaceous (Cenomanian) age.
[2] After W. B. Clark and others, Maryland Geol. Survey.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.	Recent.				Human remains. "Vermetus rock", beach sands, Coquina, aeolian, lacrustine, chemical and alluvial deposits.
Quaternary.	Pleistocene.	Palm Beach. Miami. Key Largo. Key West. Lostmans River.[1]			Yellow sand, "Vermetus rock", Coquina, „Planorbis rock", gray sand, and fossiliferous marl.
				10—30	Light colored limestone, oolitic or coralline, with sandy beds and loose sand *(Chione cancellata)*.
		Unconformity.			
Tertiary.	Pliocene.	Lafayette, etc. Bone Valley. Alachua. Nashua. Caloosahatchee.[1]		3—15	Variable beds of clay, marl and sand with some pebbles, — colors usually red, yellow, or white. (*Elephas columbi, Aphelops fossiger, Mastodon floridanus, Machairodus floridanus, Procamelus major*, etc.).
		Unconformity (?).			
	Miocene.	Jacksonville. (East Coast.)		30—140	Light gray to white limestone. Light gray to yellow clay and gray sand. Some chert beds. *(Pecten Jeffersonius, Arca limula, Venus rileyi)*.
		Unconformity.			
		Apalachicola group. Alum Bluff.		41±	Gray to green sand, clay and fuller's earth. Impure limestone occurs in some localities *(Carolia Floridana)*.
		Apalachicola group. Chattahoochee. (West Fla.) Tampa. (South Fla.) Hawthorne. (Central Fla.)[1]		30—60	Light yellow to gray, earthy and siliceous limestone, sometimes cherty, with greenish clay (*Cassidulus, Orthaulax pugnax*, etc.).
		Unconformity.			
	Oligocene.	Ocala.		0—12+	Soft, porous, light gray to white limestone with beds of marl and layers of chert. (*Nummulites* and mollusks).
		Vicksburg group. "Peninsular". (Central Fla.) Marianna. (West Fla.)[1]		100+	Soft, porous, light gray to white limestone, containing marl beds and layers of chert (*Orbitoides mantelli, Pecten paulsoni*, and *P. perplanus*).



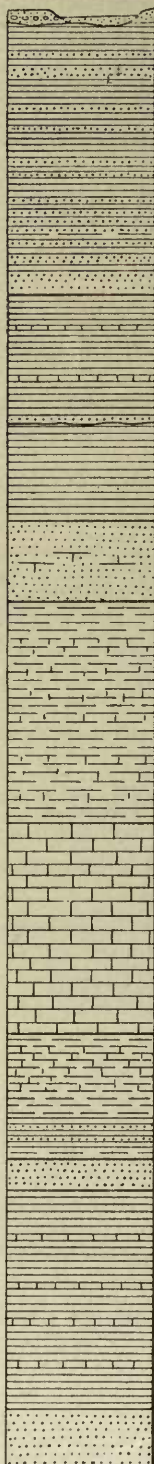
GENERALIZED TABLE OF FLORIDA FORMATIONS.[2]

[1] Contemporaneous formations in different localities.
[2] Adapted after E. H. Sellards, Florida Geol. Survey, 1909.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.				3—6	Coast sands and alluvium; alluvial deposits of the streams; soils. Coast deposits; lower terraces of the rivers; upper terraces of the rivers (surface deposits).
Plio-cene.		Lafayette. ("Orange Sand.")		8—60	Buff to orange sand and sandy clay with local beds of gravel.
Miocene.		Pascagoula.		60±	Greenish blue estuarine clay *(Gnathodon Johnsoni).*
Miocene.		Grand Gulf.		150+	Yellow, gray and black sand, sandy clay, and blue clay, with thin beds of lignite. (Fossils rare. *Unio, Cardium Chipolanum* and plants).
Eocene.	Middle-Upper.	St. Stephens. (Jackson.)		60–107	White limestone; hard and crystalline above, somewhat chalky below. *(Orbitoides mantelli, Spondylus dumosus,* and *Zeuglodon cetoides*).
Eocene.	Middle-Upper. Claiborne.	Claiborne (proper).		46	Marl, sand and soft limestone. (*Ostrea sellaeformis, Venericardia planicosta,* etc.).
Eocene.	Middle-Upper. Claiborne.	Buhrstone.		90	Massiv sandstone.
Eocene.	Lower.	Hatchetigbee.		53	Gray and buff sandy clay and sand.
Eocene.	Lower. Lignitic or Wilcox.	Bashi or Wood's Bluff.		24—26	Marl *(Ostrea compressirostra).*
Eocene.	Lower. Lignitic or Wilcox.	Tuscahoma or Bell's Landing.		43	Gray to red sandy clay.
Eocene.	Lower. Lignitic or Wilcox.	Nanafalia.		60	Sandstone and sandy clay *(Gryphaea thirsae).*
Eocene.	Lower. Lignitic or Wilcox.	Naheola.		40—46	Gray and micaceous shale *(Nucula magnifica).*
Eocene.	Lower. Lignitic or Wilcox.	Sucarnochee or Black Bluff.		30	Sand and lignite.
Eocene.	Lower.	(Midway) Clayton.		8—60	Calcareous clay and crystalline limestone *(Enclimatoceras Ulrichi).* Hard brownish yellow sandstone (*Turitella ortoni, Venericardia planicosta, Ostrea compressirostra,* etc.).
Cretaceous (Upper).		Ripley.		76—84	Gray micaceous sands interbedded with calcareous clays (*Exogyra costata,* etc.).
Cretaceous (Upper).		Selma. ("Rotten limestone.")		0—300	Soft argillaceous limestone.
Cretaceous (Upper).		Eutaw.		90	Yellow and gray sands with beds of gray calcareous clay and fine conglomerate.
		Unconformity.			
Comanchean.		Tuscaloosa.		300	Mixt sands and clays of gray, green and purplish colors. Base generally conglomeratic. (Fossil plants).
		Angular unconf.			
					(Folded Paleozoic and older rocks).

FORMATIONS OF THE COASTAL PLAIN IN ALABAMA.[1]

[1] Compiled chiefly from reports of E. A. Smith, Alabama Geol. Survey.



Per.	Div.	Formation.	M.	Description.
Quaternary.			6	Red and gray sand, clay, gravel.
Eocene.		Wilcox. ("Sabine.")	130	Dark lignitic sand and clay, with calcareous boulders.
Eocene.		Midway.	60	Dark clay, with a limestone bed here and there.
		Unconformity?		
(Upper) Cretaceous.	Gulf Series.	Arkadelphia.	45	Dark stiff clay.
(Upper) Cretaceous.	Gulf Series.	Nacotach.	36	Sand with beds of sandstone. Contains petroleum.
(Upper) Cretaceous.	Gulf Series.	Marlbrook.	100	Blue marl, with chalky layers ("Saratoga" chalk).
(Upper) Cretaceous.	Gulf Series.	Austin group. Annona.	1[illegible]0	Chalk with many fossil fragments, often with strong odor of petroleum.
(Upper) Cretaceous.	Gulf Series.	Austin group. Brownstown.	60	Clay, marl, chalk, and sand, with hard pyritic layers.
(Upper) Cretaceous.	Gulf Series.	Eagle Ford.	120	Tough blue clay with hard limestone and pyritic layers. Sand (15 m.) at the top.
(Upper) Cretaceous.	Gulf Series.	Woodbine.	30 +	Sand, containing salt water and oil.

FORMATIONS OF CENTRAL LOUISIANA.[1]

[1] After G. D. Harris, U. S. Geol. Survey, 1910.

in the Cretaceous. Beds of Eocene and Oligocene age are the oldest known in the peninsula of Florida.

Miocene rocks are widely distributed on the Atlantic portion of the plain, and there they rest unconformably upon all older rocks. The Chesapeake formation consists of marine sands and clays. In Florida the equivalent formation is chiefly limestone. Along the Gulf of Mexico Miocene rocks appear at the surface but rarely, altho their existence has been made known by borings near the coast. They are broadly overlapt by younger formations.

Pliocene beds have been identified only here and there in the Coastal Plain. There is a thin limestone of this age in Florida, and there are local deposits of marl with Pliocene fossils along the Atlantic coast. A widespread formation of sand and gravel (Lafayette formation) which seems to be of terrestrial origin, is generally referred to the Pliocene, altho it contains no distinctiv fossils, and by some geologists is assigned to the Pleistocene.

The Quaternary deposits are largely non-marine, except in Florida where there is recent limestone. Along the Mississippi embayment considerable deposits of Quaternary alluvium and loess cover the present surface, and the other streams which cross the Coastal Plain are generally bordered by plains and terraces of Quaternary river deposits.

Structure.

The Structure of the Coastal Plain is simple. All the beds are essentially conformable in dip, altho interrupted by eroded surfaces. Their gentle inclination to-

Fig. 27. Profile of the Atlantic Coastal Plain in the vicinity of Washington, D. C.:—C, unconsolidated Comanchean and Cretaceous sediments, resting upon schistose pre-Silurian rocks; Q, Quaternary gravel and sand. (U. S. Geol. Surv.)

ward the Atlantic Ocean and Gulf of Mexico may be largely the initial dip of deposition. Evidences of subsequent deformation are scarce. In Alabama the Cretaceous rocks show gentle flexures and occasional normal faults of small throw. In central Texas the Cretaceous beds have been broken along an extensiv fault zone but only the downthrown portion is now considered a part of the Coastal Plain. In Louisiana and Texas there are peculiar little mounds in the vicinity of which the strata have high dips and show considerable alteration; but the origin of these is still in doubt. They may be due to the crystallization of salt in small lenses. Except for some small necks of late Cretaceous phonolite and basalt on the border of the province in western Texas and peridotite in central Arkansas, the Coastal Plain seems to be free from igneous rocks.

Geologic History.

Before the Jurassic period the site of the Coastal Plain had past thru a varied history. The eastern portion of it had been folded at the close of the Permian and later subjected to warping, faulting, and locally to volcanic activity. There is evidence that thruout its entire extent, however, it had been nearly base-levelled before the end of the Jurassic. Beginning at that time the planated surface was covered alternately by advancing sheets of terrestrial sediments and at other times by marine deposits. Occasionally, at times of emergence, it was subject to exposure and erosion, but the denudation seems never to have cut deeply. The most extensiv submergences were those of the Cretaceous and Eocene periods and, in the eastern portion of the plain,

the Miocene. The region now occupied by the peninsula of Florida seems to have been submerged until Tertiary times. It is a very low fluted arch believed by Vaughan[1] to be the result of repeated mild warpings extending from late Eocene to Quaternary time.

Physiography.

Inasmuch as nearly all of the Coastal Plain seems to have been covered by late Tertiary sediments, the topography, at least in the eastern portion, is largely of post-Pliocene age. The present relief features have been carved from the slightly up-lifted plain almost entirely by sluggish transverse rivers. The loose sediments offer so little resistance that wide flat valleys have been quickly excavated and the bounding slopes

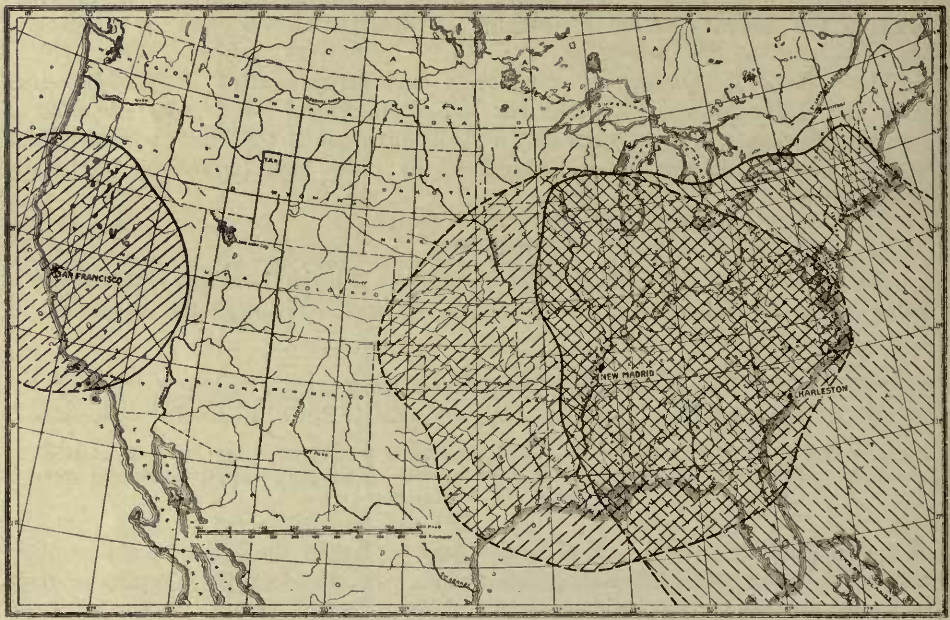


Fig. 28. Sketch map showing the areas over which three of the principal American earthquakes were felt.

are usually gentle. Slight differences in the resistance of certain formations in the plain have permitted more rapid denudation along the outcrops of the softer strata, leaving between them one or more low, asymmetrical ridges—cuestas—which form divides between the minor streams of the Coastal Plain. The individual valleys are bordered by several sets of terraces which show that the downward cutting has been intermittent. These changes in the rate of excavation may well be due largely to the known changes in the relativ elevation of the land and sea. The lower courses of the rivers have been very recently submerged and, in consequence, the upper reaches are now being partly filled with alluvium.

Seismicity.

The Coastal Plain is seismically somewhat anomalous, for, altho it is generally undisturbed, it includes the sites of two of the most destructiv earthquakes recorded in the United States.

[1] Vaughan, T. W., Sketch of the Geology of the Floridian plateau. Science, N. S., Vol. 32, pp. 24—27, 1910.

The older of these, the New Madrid earthquake of 1811—12 was generated in the upper part of the Mississippi embayment, and has already been described as belonging in part to the Interior Lowlands element (p. 120).

In 1886 a disastrous earthquake partly destroyed Charleston, South Carolina, and was felt over nearly all of the eastern part of the United States (see map). It is remarkable in having apparently had a double center. The cause of this as well as of the earlier earthquake, is unknown. In addition to these two shocks of the first magnitude a few smaller and not destructiv quakes have been felt in various parts of the Coastal Plain, but they may be considered rare.

Rocky Mountains Element.

General.

This large ill defined element embraces the Rocky Mountains, which cross the western part of the United States from the states of Montana and Idaho south to New Mexico and perhaps to western Texas.[1] Northwestward it merges into the Cascade province in Washington, and southward into the broken Colorado plateaus, the boundaries in both places being indefinit.

Topographically the Rocky Mountains consist of a plateau, 1500 to 2500 meters high in Colorado and New Mexico but somewhat lower in the north, upon which are superimposed ranges of mountains with peaks rising to more than 4300 meters.

The climate is relativly dry, the northern part being subarid, while the south is essentially a desert. Corresponding to this there is a much more extensiv forest cover upon the mountain slopes in the north, less in the middle and but little in the south.

The rocks of which the Rocky Mountains are composed include strata of nearly all periods from Archeozoic to recent. The Archeozoic and earlier Proterozoic rocks are metamorphosed. Upon them lies a great succession of sedimentary beds ranging from late Proterozoic to Cretaceous. These are interrupted by many unconformities, but there is generally little discordance of bedding. The entire sequence has been moderately folded and faulted and locally intruded by volcanic rocks. Upon the eroded surface of all these beds rest local terrestrial deposits of Tertiary and Quaternary age, including the moraines of local glaciers. Scattered irregularly thru the province there are vast quantities of Tertiary eruptivs.

Stratigraphy.

Metamorphic Rocks. The oldest rocks, referred in part to the Archean system and in part to the early Algonkian, are exposed generally in the cores of anticlinal ranges and along the bases of fault blocks. Gneisses and schists of great variety, highly folded and often difficult to interpret lie at the base. Into these have been intruded various kinds of igneous rocks of many generations, particularly batholiths of red granite, leaving a complex which in many places is most intricate. The metamorphic quartzites and limestones which are definitly of sedimentary origin it is customary to regard as early Algonkian. If this be the correct view, many of the igneous rocks must be Algonkian also. Rocks demonstrably older than these sediments have not been found.

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[1] There is an alternativ view favored by J. W. Powell, E. Suess and others, which considers that the Rocky Mountains end with the Santa Fe range in northern New Mexico, while the region farther south is variously regarded as a part of the Colorado plateaus or of the Basin Ranges or of the plateau province of Mexico.

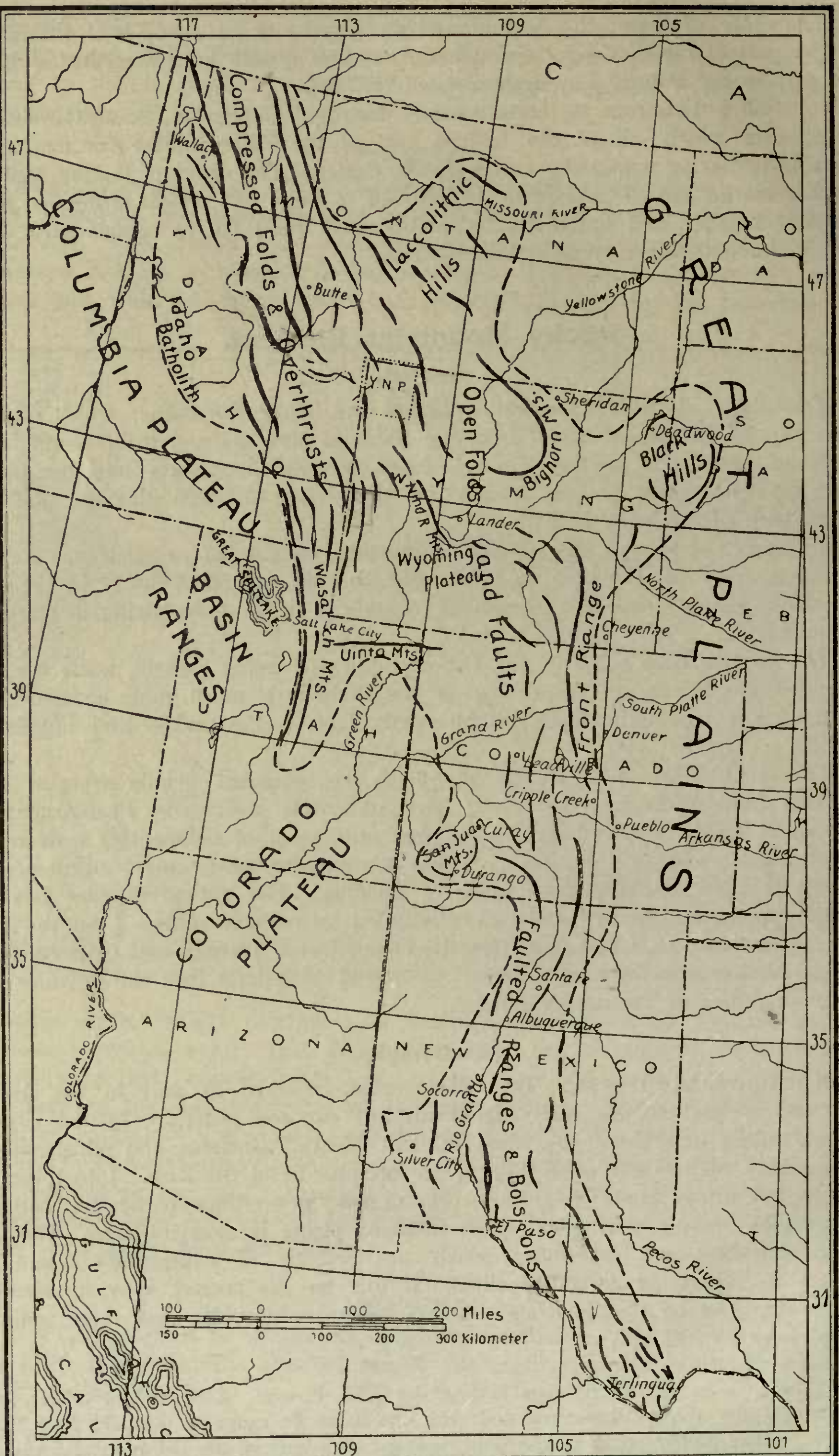


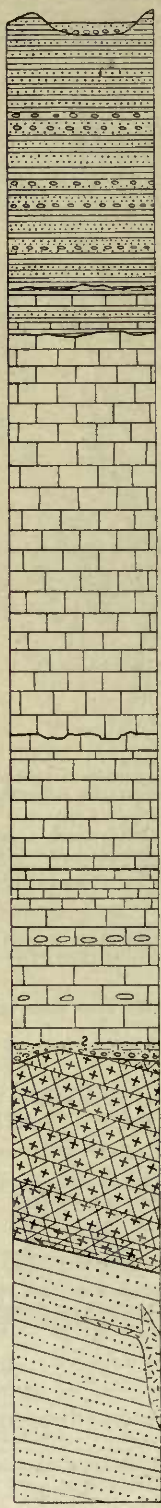
Fig. 29. Sketch map of the Rocky Mountains Element.

Per.	Div.	Formation.	Strata.	M.	Description.
Pleistocene.		Alluvium.		15	Sand, gravel and clay.
		Glacial.		30	Sand, boulders and unassorted material.
		Unconformity.			
Miocene.	Upper.	Bozeman.		550—750	Sand, conglomerate, limestone, clay and volcanic dust.
		Unconformity.			
Eocene.		Sphinx.		600—900	Conglomerate of limestone pebbles cemented by reddish sand.
		Angular unconf.			
?		Livingstone.		300	Conglomerate, sandstone, shale and andesitic tuff (perhaps basal Eocene).
		Unconformity.			
Cretaceous.		Laramie.		250—300	Gray sandstone and clay, with coal beds (fossil plants).
		Montana and Colorado.		550—600	Dark shale and sandstone.
		Dakota.		250—300	Conglomerate, quartzite or sandstone, and shale. At the top a thin bed of limestone with freshwater gastropods.
Jurassic.		Ellis.		100—150	Arenaceous limestone above, argillaceous limestone near the middle, and quartzite at the base. (Marine upper Jurassic fossils).
Carboniferous.	Upper.	Quadrant.		100—150	Red magnesian limestone, overlain by cherty limestone and quartzite.
	Lower.	Madison.		360—450	Jaspery limestone above, massiv gray limestone near the middle, and laminated limestone below.
Devonian. & ? Silur.		Three Forks.		45—60	Orange, green and black shale and gray magnesian limestone.
		Jefferson.		200—300	Massiv black limestone and crystalline dolomite (*Atrypa reticularis*, etc.).
Cambrian. & ? Ordovic.	Middle-Upper.	Gallatin.		120—150	Pebbly limestone above, shale in the middle, and mottled yellow and gray limestone below (*Obolella*).
		Flathead.		150—200	Greenish shale. Massiv limestone.
		Angular unconf.		40	Green shale and glauconitic limestone (middle Cambrian fossils). Brown quartzite and sandstone.
Algonkian.	Upper.	Belt.		2000—3000	Argillite, arenaceous limestone, micaceous sandstone, with dark gray quartzite, arkose and conglomerate below.
		Angular unconf. (?).			
	Lower.	Cherry Creek.		?	Marble and quartzite with interbedded gneiss and mica-schist.
		Angular unconf. (?).			
Archean.					Gneiss and schist.

SECTION IN SOUTHWESTERN MONTANA.[1]

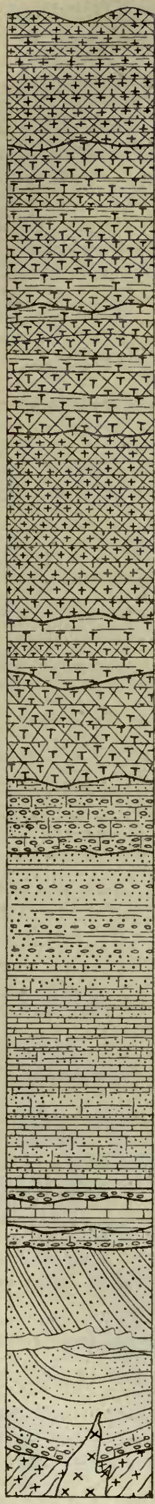
[1] Near Bozeman, Mont.; slightly modified after A. C. Peale, U. S. Geol. Survey, 1896.

Per.	Div.	Formation.	M.	Description.
Quaternary (possibly Tertiary in lower part).		River alluvium.	30±	Gravel, sand, and clay in flood plain of Rio Grande.
Quaternary (possibly Tertiary in lower part).		Bolson deposits.	600+	Clay, sand, gravel and caliche in Hueco bolson.
		— Angular unconf. —		
Cretaceous.	Upper.	Colorado.	8+	Drab shale (sequence concealed. (*Inoceramus labiatus*).)
Cretaceous.	Lower.	Comanche.	90+	Gray limestone, shale and sandstone (sequence concealed). (*Exogyra texana, Trigonia emoryi*).
		— Unconformity. —		(Permian limestone and red beds eroded off in this locality).
Pennsylvanian.		Hueco.	900+	Massiv gray limestone (*Spirifer rockymontanus, Productus cora, P. semireticulatus, Composita, Fusulina, Hustedia*, etc.).
		— Unconformity. —		
Silurian.		Fusselman.	300±	Massiv light to dark magnesian limestone (*Favosites, Pentamerus?, Amplexus*, etc.).
Ordovician.	Upper-Middle.	Montoya.	60–120	Massiv dark magnesian limestone. (Fossils below: *Receptaculites oweni*, etc. Above: *Rhynchotrema capax, Dinorthis subquadrata*).
Ordovician.	Lower.	El Paso.	300±	Massiv gray magnesian limestone, with local cherty beds (*Ophileta, Cameroceras*).
		— Local unconf. (?). —		
Cambrian.		Bliss.	0–90	Brown and gray indurated sandstone, with conglomerate at the base. (*Lingulepis acuminata*).
		— Angular unconf. —		
Pre-Cambrian.	Proterozoic (?).	Rhyolite.	450±	Massiv red rhyolite porphyry with rhyolitic agglomerate at the base.
Pre-Cambrian.	Proterozoic (?).	Lanoria.	550±	Light and dark quartzite cut by thin sill and dikes of diabase.



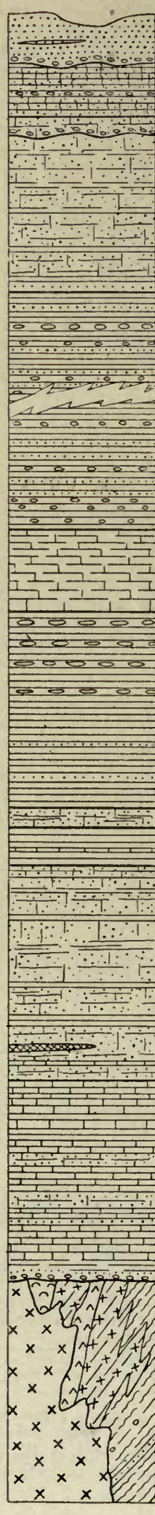
SECTION NEAR EL PASO, WEST TEXAS.[1]

[1] After G. B. Richardson, U. S. Geol. Survey, 1909.

Per.	Div.	Formation.	Strata.	M.	Description.
Tertiary.		Silverton. Potosi.		380	Alternating rhyolite and quartz-latite flows and tuffs, — flows predominating near base.
		— Unconformity. —			
				30—900	Andesitic flows, tuffs, and dikes, with both augite and hypersthene.
		Unconformity. —			
		Burns.		365	Flows, tuffs, breccias, and dikes of dark hornblendic quartz-bearing latite.
		Unconformity. —			
		Eureka.		550	Massiv rhyolite flows, dikes, and bedded tuffs, the first greatly predominating.
		Unconformity. —			
		Picayune.		150	Augite-andesite tuff, breccia, or agglomerate, and massiv flows.
		Unconformity. —			
		San Juan.		30—600	Almost exclusively andesitic debris.
		— Unconformity. —			
		Telluride.		100—300	Contains pebbles and bowlders of schist, granite, and quartzite, with some Paleozoic limestones, etc. Includes beds of sandstone and shale.
		— Unconformity. —			
Permian (?).		Cutler.		300	Bright red sandstone and pinkish grit and conglomerate, alternating with reddish sandy shale and limestone.
Pennsylvanian.		Rico.		90	Dark red-brown sandstone and pink grit, with intercalated greenish or reddish shale, and sandy limestone.
		Hermosa.		600	Limestone, grit, sandstone, and shale. Heavy bedded limestone predominates in middle and upper parts, sandstone and shale below. Fossils numerous. (*Meekella striata-costata, Chonetes mesolobus, Spirifer cameratus, Productus nebraskensis*, etc.).
		Molas.		23	Red calcareous shale and sandstone, with thin fossiliferous limestone lenses, and pebbles of chert, limestone, and quartzite (*Rhippidomella pecosi*).
Devonian.	Upper.	— Unconformity. —			
		Ouray.		60	Pale yellow to buff, compact limestone; lower third shaly, with thin quartzites; abundant fossils indicate Devonian age of lower two thirds (*Camarotoechia endlichi* and *Spirifer disjunctus*), but the upper part may be Mississippian.
		Elbert.		8—30	Thin limestone, sandstone, and calcareous shale; fragmentary remains of fishes (*Bothriolepis*).
		— Unconformity. —			
Cambrian.		Ignacio.		0—60	Light gray, pink or yellow quartzite; massiv and conglomerate below, thin-bedded with shale or sandy partings in medial zone, massiv above (*Obolus sp.*).
		Unconformity.			
Proterozoic.		Uncompahgre.		2440	Massiv white or smoky quartzite and dark slate, alternating in thin beds locally. No fossils found.
Archeozoic.					Schist and gneiss of light and dark colors, often alternating. Intruded by granite and cut by basic dikes, many of which have been masht.

GENERALIZED SECTION OF STRATA IN SOUTHWESTERN COLORADO.[1]

[1] After W. Cross and E. Howe, U. S. Geol. Survey, 1907.

Per.	Div.	Formation.	Strata.	M.	Description.
Tertiary.	Miocene.	Arikaree.		6—75	Sand, gravel, and boulder beds, with local limestone lenses (*Promerycochaerus, Diceratherium*, etc.)
		— Unconformity. —			
	Oligocene.	White River group: Brule.		75	Massiv pinkish sandy clay, with gravelly streaks (*Oreodon, Hyracodon, Leptauchenia*, etc.).
		White River group: Chadron.		6—30	Massiv brown sandstone, merging into sand and gravel (*Titanotherium*).
		— Unconformity. —			
Upper Cretaceous.	Montana.	Fox Hills.		215	Gray sandstone and sandy shale.
		Pierre.		1525	Dark gray shale, with fossiliferous concretions, and thin beds of sandstone.
	Colorado.	Niobrara.		100—122	Impure chalky limestone and gray limey shale (*Inoceramus deformis, Ostrea congesta*, etc.). Massiv gray limestone at base.
		Benton.		215—305	Gray shale containing dark concretions (*Prionocyclus, Prionotropis*, etc.), with gray sandstone near the top. Hard gray shale (fish scales). Dark gray shale and thin sandstones.
Lower Cretaceous.		Cloverly.		21—30	Hard gray sandstone and purple to gray sandy clay (upper part perhaps upper Cretaceous).
		Morrison.		45—60	Massiv pale green to maroon shale with thin beds of limestone and sandstone.
Jurassic.	Upper.	Sundance.		9—18	Buff slabby sandstone and sandy gray shale (*Belemnites densus, Gryphea calceola, Pentacrinus asteriscus*, etc.).
		Unconformity (?).			
Triassic or Permian (?).		Chugwater.		240—305	Red sandy shale, fine-grained massiv sandstone, mostly red, and thin beds of limestone and gypsum near the base (no fossils).
Pennsylvanian.		Casper.		240—305	Gray to red sandstone, gray to purple limestone (*Spirifer cameratus, Productus cora*, etc.) and red shale. Gray to reddish-brown sandstone and fine conglomerate at the base.
		— Unconformity. —			(Smooth surface on deeply decayed rocks).
Pre-Cambrian.		Sherman.			Coarse-grained pink granite, batholith intruded into all the older rocks
		Intermediate instrusives.			Syenitic, gabbroic and dioritic intrusives, and anorthosite.
		Granite-gneiss.			Gray to pink gneiss constituting remnants of ancient batholiths.
		Oldest schists and gneisses.			Schistose acid and basic volcanic rocks and schists of doubtful origin, some possibly sedimentary.

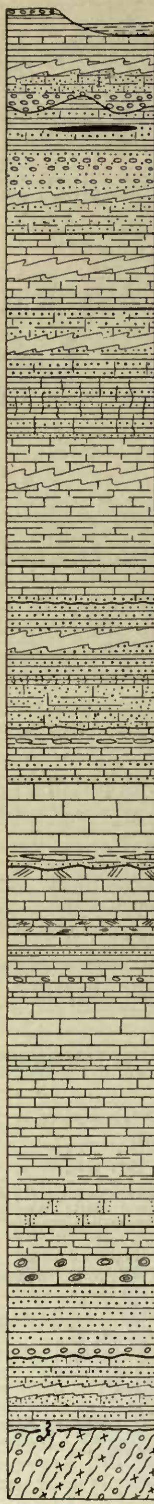
GENERALIZED SECTION OF STRATA IN THE LARAMIE MTS. OF SOUTHEAST WYOMING.[1]

[1] Modified after N. H. Darton and others, U. S. Geol. Survey, 1910.

Per.	Div.	Formation.	Strata.	M.	Description.
Upper Cretaceous.		Laramie (?).		685	Gray sandstones and carbonaceous shales, with lignite deposits. (May include basal Eocene).
Upper Cretaceous.		Fox Hills (?).		70	Soft, massiv buff sandstone, with harder, darker concretions.
Upper Cretaceous.		Pierre.		300—800	Dark gray shale, with concretions.
Upper Cretaceous.		Colorado.		300—400	Gray shales; thin brown sandstones below; hard, fine gray sandstones and shales (Mowry beds) in the middle, concretions with *Prionocyclus*, etc., and massiv buff sandstone at top.
Lower Cretaceous	- ? -	Cloverly.		40	Coarse, massiv buff sandstone below, with purplish and gray shale and some sandstone above. No fossils.
Lower Cretaceous	- ? -	Morrison.		60	Massiv shale, greenish gray, buff, and maroon, with thin sandstone beds. No fossils.
Jurassic.		Sundance.		60	Soft sandstones, overlain by greenish-gray shale; several hard fossiliferous limestone layers near top and bottom (*Camptonectes bellistriatus, Belemnites densus*, etc.).
Triassic. ?		Chugwater.		245	Red shale and soft maroon sandstone; thin limestone layers near top and bottom, and gypsum deposits near top. No fossils.
Permian. ?	- ? -	Embar.		75	Gray limestone and shale, with cherty beds. (*Spiriferina pulchra* and bryozoans).
Pennsylvanian.		Tensleep.		60	Massiv buff to gray sandstone.
Pennsylvanian.		Amsden.		75	Red shale at base, overlain by fine-grained white limestone; sandstone, shale and cherty limestone near top.
		? Unconformity.			
Mississippian.		Madison.		170	Light colored dense limestone, very massiv near top. (*Spirifer centronatus, Chonetes loganensis*, etc.).
Ordovician (in part).		Bighorn.		12—45	Hard, massiv dolomite, buff to white. (*Halysites catenulatus, Zaphrentis*, etc.).
Cambrian.	Middle.	Deadwood.		0—30	Slabby limestone and flat-pebble limestone conglomerate.
Cambrian.	Middle.	Deadwood.		120—150	Green shale with bed of limestone near base.
Cambrian.	Middle.	Deadwood.		60—90	Sandy shale with sandstone near base.
Cambrian.	Middle.	Deadwood.		15—30	Massiv, brown sandstone.
		Angular unconf.			
Pre-Cambrian.		Granite.			Gray and red granitic rocks, penetrated by diabase and other dikes.

PRE-TERTIARY FORMATIONS IN THE OWL CREEK MOUNTAINS, CENTRAL WYOMING.[1]

[1] Slightly modified after N. H. Darton, U. S. Geol. Servey, 1906.



Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.					Lake beds and river alluvium and local glacial moraines. High-level gravels on plateaus and terraces.
		— Unconformity. —			
Tertiary.	Lower Eocene.	Wasatch.		900	Tuffaceous conglomerate, sandstone, shale, and fresh-water limestone (*Coryphodon*).
		— Unconformity. —			
Comanchean (Lower Cretaceous).		Bear River.		300	Dark shale, sandstone, conglomerate, and some limestone. Contains beds of impure coal. (*Unio belliplicatus, Pyrgulifera humerosa*, etc.)
		Beckwith.		1500	Coarse conglomerate, white to yellowish calcareous sandstone and sandy shale.
Jurassic.		Twin Creek.		1000±	Limestone, generally thin-bedded or shaly, with some massiv strata (*Camptonectes bellistriatus, Trigonia quadrangularis*).
- ? -		Nugget.		580	Massiv red and white sandstone and red sandy shale. The greater part is of dark-red or brown color, altho in places an upper zone is distinct as a clear white sandstone. Includes intervals of sandy shale.
Triassic.		Ankareh.		215—460	Red shale and flaggy sandstone.
		Thaynes.		600	Gray argillaceous limestone, (*Myalina permiana, Meekoceras, Aviculopecten curtocardinalis*, etc).
- ? - Permian.		Woodside.		300	Red micaceous shale, much ripple-markt, buff and gray shale and flaggy limestone (*Lingula*).
Pennsylvanian.		Park City.		200±	Limestone, shale, chert and phosphate rock, white basal sandstone and breccia (*Productus nevadensis, Spiriferina pulchra*).
		— Unconformity. —			
		Weber.		1200±	Cream white quartzite, with thin beds of dark siliceous limestone in lower portion.
- ? - Mississippian.		Morgan.		300±	Red shale and pink sandstone, with a few beds of gray limestone (*Productus nebraskensis, Spirifer rockymontanus*, etc.)
		— Unconformity. —			
	Upper			300+	Dark shale, brown, gray and pink limestone and sandstone (*Productus cestriensis, Spirifer keokuk*, etc.)
	Lower.	Madison.		350	Black limestone (*Spirifer centronatus, Composita subtilita, Chonetes logani, Proetus peroccidens*, etc.
- ? - Devonian.		?		100	Buff, red and gray shale and dolomite.
		— Unconformity. — Jefferson.		300±	Drab dolomite. Blackish limestone. (*Atrypa reticularis*).
Silurian.		Paradise.		75+	Light gray dense limestone and crystalline dolomite (*Pentamerus, Halysites*. etc.
Ordovician.		Box Elder.		150—610	Gray limestone and calcareous conglomerate, with local green shale and yellow quartzite. (*Bathyurus, Orthis calligrama?*, etc.
Cambrian.	Upper.	St. Charles.		295	Massiv bedded limestone.
				80	Thin-bedded limestone.
	Middle.	Nounan.		317	Friable gray limestone.
		Bloomington.		402	Gray and bluish gray limestone with a few bands of shale.
		Blacksmith.		174	Dark arenaceous limestone.
		Ute		147	Thin-bedded gray limestone and shale.
		Spence.		9	Argillaceous green shale.
		Langston.		152	Thick-bedded gray orbicular limestone.
	- ? - Lower.	Brigham.		400	Cream to gray quartzite with basal conglomerate.
		— Unconformity. —			
Algonkian (?)				3000+	Alternating buff, gray, purple, and red quartzite, brown graywacke and maroon and green slate.
		— Unconformity (?). —			Not observed.
Archean.					Complex of schist, gneiss, etc.

GENERALIZED SECTION OF ROCKS BETWEEN SALT LAKE AND BEAR LAKE, UTAH.[1]

[1] Compiled largely from writings of C. D. WALCOTT, H. S. GALE and E. BLACKWELDER, 1905—1910.

The Folded Sedimentary Rocks. The moderately folded and unmetamorphosed sedimentary series rests in markt unconformity upon the older rocks. Altho containing formations of many different ages separated here and there by minor unconformities, the series may be broadly considered a unit. The Paleozoic part of the sequence is much thinner on the east side of the province than on the west, where it partakes of the character of the Basin Ranges section.

At the base lies a thick sequence of quartzite with slate and subordinate amounts of limestone, all believed to be of late Proterozoic age. Traces of fossils thought by WALCOTT[1] to include eurypterids, worms and brachiopods have been found in them in Montana, but these are insufficient for correlation. They are rarely associated with igneous rocks. From the lack of fossils, the prevalence of ripple-marks, suncracks, and other lithologic peculiarities it is suspected that the series consists largely of subaerial deposits.

Upon the Algonkian quartzite series, which is slightly, or locally considerably, folded, the Cambrian and later systems rest unconformably. In the southern, central and northeastern parts of the Rocky Mountains element the Cambrian is thin and in some places entirely lacking. It is generally represented by sandstone or quartzite passing upward into shale and even limestone. It is believed to include only the middle and upper part of the Cambrian system. Northwestward, however, from eastern Utah to western Montana the Cambrian rocks are much thicker and include several hundred meters of limestone. The Cambrian of this part of the province resembles that of the Basin Ranges.

Middle Paleozoic strata, from Ordovician to Devonian, are generally lacking in the central Rocky Mountains, altho in eastern Colorado there is a thin Ordovician limestone and in western Colorado an upper Devonian limestone. In the extreme south, however, the Paleozoic section seems to be complete; and again in the northern and northwestern parts of the Rocky Mountains no important interruption in the sedimentary column of the middle Paleozoic has been proved. In Montana the Ordovician, Silurian, and Devonian periods are represented usually by dark limestone which contains but few fossils. For that reason the existence of the Silurian was not recognized by the first students of the region, and both Ordovician and Devonian systems are generally hard to identify.

The upper Devonian and Carboniferous periods are represented by more widespread and better known formations. Limestone is the prevalent rock. The base of this stands at a variable horizon. In western Colorado it is Devonian. In the central part of the same state it seems to be Mississippian and in southeastern Wyoming it is Pennsylvanian. Within the limestone there are local unconformities, the one which separates Mississippian from Pennsylvanian being most widespread. These limestones contain an abundance of fossils of the Pacific realm, and in the extreme south a rich Permian fauna has been made known by GIRTY.[2]

The Carboniferous limestones and quartzites are followed by the Red Beds. On the east flank they are chiefly of Permian and Triassic age but pass down in some places into the Pennsylvanian and doubtless range upward into the Jurassic; in the western ranges of Wyoming and Idaho they are believed to be late Triassic and Jurassic. The rocks are brick red earthy sandstones and sandy shales with which are interbedded thin layers of gypsum. As the beds are generally devoid of fossils, to this fact is due the uncertainty as to their age. In central and southeastern Wyoming Triassic amphibians and reptiles have been found in the upper part of the Red Beds.

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[1] WALCOTT, C. D., Pre-Cambrian Fossiliferous Formations, Bull. Geol. Soc. of Am. X, 1899, pp. 199—244.

[2] GIRTY, G. H., The Guadalupian fauna, U. S. Geol. Survey, Prof. Paper 58, 1908.

Locally they rest unconformably upon the limestone beneath, but elsewhere they seem to intergrade with them.

Upon the Red Beds rest conformably or with a very obscure unconformity a thick sequence of gray, green and yellow sediments of upper Jurassic to late Cretaceous age. The average thickness of these beds is not less than 3000 meters and the maximum is much more. The late Jurassic[1] rocks consist of gray shale and limestone containing a North Pacific or Arctic marine fauna of brief reign. This is followed by the Morrison formation, which seems to be transitional from the Jurassic to the Comanchean; and that is followed in turn by sandstones and shales containing Comanchean plants and locally coal seams. The Cretaceous beds (upper Cretaceous) are generally conformable on the Comanchean but in some places are separated by an obscure unconformity. The basal formations, of which the best known is the Dakota, consist of sandstone or conglomerate with the leaves of angiosperm plants. The sandy beds pass up into the Colorado shales containing marine fossils, and in the midst of the shales there is more or less chalk along the eastern border. In the western part of the Rocky Mountains the middle Cretaceous beds are more largely non-marine and coal-bearing than on the east. The uppermost and thickest part of the Cretaceous system consists of alternating sandstones and shales with many coal beds. The fossils in these are brackish-water or fresh-water shells with abundant plant remains and the bones of land reptiles and archaic mammals.

Between the Cretaceous and the undoubted Tertiary strata, which are generally separated in the mountains by a conspicuous unconformity, there are local deposits which may be considered transitional between the two periods. Here belong the "Ceratops (or Lance) beds" of Wyoming and the Denver and Arapahoe formations of

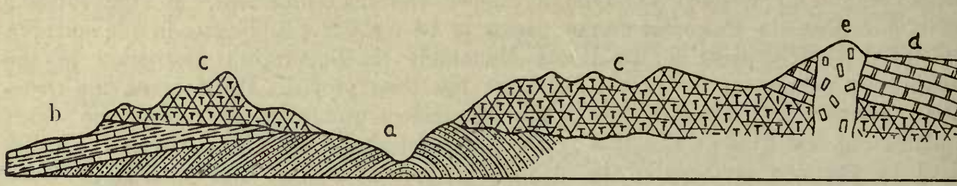

Fig. 30. Profile in the Rocky Mountains near Silverton, Colo.: a, Proterozoic quartzite and slate; b, Carboniferous limestone and shale; c, San Juan tuff; d, volcanic flows and breccia; e, porphyry stock. (After W. Cross and others, U. S. Geol. Surv.)

Colorado. The latter are coarse sediments associated with much volcanic material and generally separated from the marine Cretaceous by an unconformity. In some of these formations dinosaur bones have been found associated with plants of Eocene aspect, and so there is still some dispute as to their correlation. The widespread Fort Union formation of Montana and its correlativs in adjacent states should perhaps be placed here; it contains basal Eocene mammals and a well defined early Tertiary flora, but it is involved in the folding of older rocks and is unconformably overlain by early Eocene strata.

Superficial Sediments and Volcanics. The Tertiary and Quaternary formations form a distinct series. In the mountains they lie unconformably upon all the older rocks and generally occupy synclinal depressions. They consist of conglomerate, sandstone and shale with many local deposits of volcanic tuff, breccia and lava. That they are continental in origin is indicated by the abundant land mammals which have

[1] Limestone and shale containing a very late Jurassic fauna of the Mexican type crosses the Rio Grande River into the western corner of Texas (Stanton, T. W., Stratigraphic notes on Malone Mountain and the surrounding region near Sierra Blanca, Texas. U. S. Geol. Surv. Bull. 266, pp. 23—33, 1905).

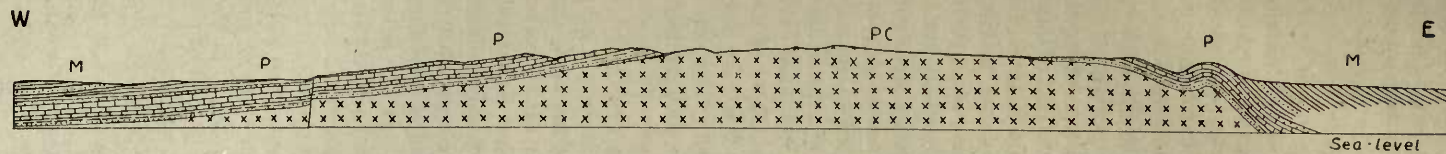

Fig. 31. Profile thru the central part of the Bighorn Mountains, Wyoming. (After N. H. Darton, U. S. Geol. Surv.) — M, Mesozoic beds, chiefly Cretaceous; P, Paleozoic limestone, shale and sandstone; Pc, Pre-Cambrian, chiefly granite and gneiss. Length of profile, 66 km.

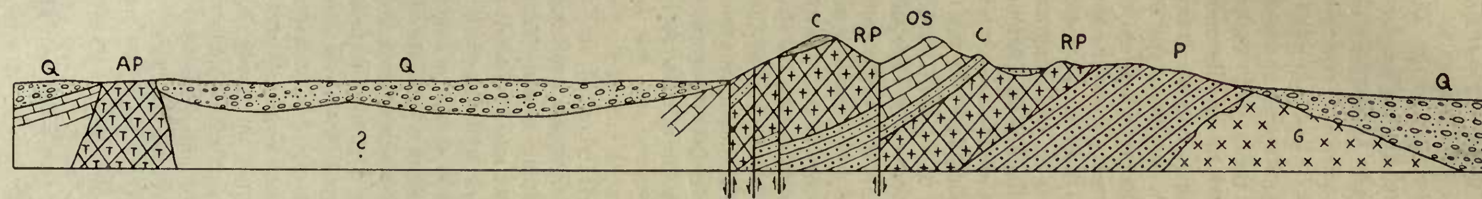

Fig. 32. Profile across the Franklin Mountains near El Paso, Texas: Q, Quaternary sand and gravel; Ap, andesite porphyry, C, Cambrian quartzite; Rp, rhyolite porphyry: Os, Ordovician-Silurian limestone; P, Proterozoic quartzite, G, pre-Cambrian granite. (After G. B. Richardson, U. S. Geol. Surv.)

Fig. 33. Profile of the Lewis and Livingstone Ranges in northwestern Montana showing Algonkian strata overthrust from the west upon Cretaceous and older rocks (after B. Willis).

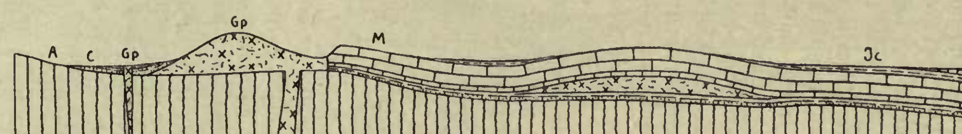

Fig. 34. Profile of laccoliths in the Little Belt Mountains of central Montana: Gp, granite porphyry dikes and laccoliths; M, Madison limestone; Jc, Jurassic and Cretaceousstrata. (After W. H. Weed and L. V. Pirsson, U. S. Geol. Surv.)

been found in them; and that they have been laid down largely by streams and only subordinately in lakes is the general verdict of recent students. In age these deposits range from Lower Eocene thru all the various divisions of the Tertiary down to recent times, and they are still in process of formation. Among the higher mountain ranges, deposits of till and outwash have been left by local Quaternary glaciers.

Structure.

In so large a region as the Rocky Mountains there is necessarily much diversity of structure. In general it may be said that the ancient rocks are intensely folded, masht and schistose. They have been intruded by granite and other igneous rocks.

The great thickness of sedimentary rocks, ranging from late Proterozoic to Cretaceous, has been moderately folded, so that a common type of structure is the isolated dome, such as that of the Black Hills, or long elliptical anticlines like the Bighorn Mountains and many others. On the flanks of these folds the dips are generally low, but locally steep. Many of the folds are broken on the sides by normal or steep overthrust faults. In the southern part of the Rocky Mountains the prevailing structure is that of tilted blocks separated by old faults. In northwestern Montana and extending into Canada, the Algonkian rocks have been thrust up and over the Cretaceous beds toward the east, making a displacement of more than 11 kilometers horizontally.[1] In the mountains of northern Utah and western Wyoming other overthrusts of importance have been reported, but in that region the movement was usually toward the west. Thruout the Rocky Mountain province there are many intrusions of igneous rocks, the majority of which are not, however, of great size. Small batholiths, stocks and laccoliths are the largest masses, and with these are associated myriads of dikes and sills. Altho these are distributed thruout the Rocky Mountain region, some districts, such as southern Wyoming, are singularly free from them. The Tertiary rocks which overlie the eroded edges of the older strata, are generally horizontal or nearly so; but in southwestern Wyoming and a few other places the older Eocene beds have been moderately folded. The older Tertiary rocks have been locally affected by igneous intrusions, but the younger beds are essentially unchanged.

Geologic History.

In the remote period before the late Proterozoic, volcanic eruptions and the deposition of sediments were followed by the folding and metamorphism of the rocks. Several generations of igneous rocks were intruded into the older series, but before the later Algonkian period the folds were planed off and the older rocks deeply eroded. In a time generally supposed to be late Proterozoic clastic sediments were spread over much of the province. This period of sedimentation was followed by mild deformation in the north, and somewhat stronger folding in southwestern Colorado. In the latter place a granitic magma was intruded into the Proterozoic rocks. The deformation was then followed by denudation which removed the Proterozoic rocks from large areas which they doubtless once covered, and produced a widespread peneplain.

Early in the Cambrian period the sea began slowly to encroach from the west, covering the northwestern edge of the region in lower Cambrian time, and almost all of the province, excepting perhaps a part of Colorado and Wyoming, in the middle Cambrian. The conformable sequence of limestone shows that much of the Rocky Mountain region remained submerged beneath the clear western sea from the Cambrian at least until the Carboniferous, except for brief withdrawals of the sea and consequent slight erosion in some localities. In the opinion of many geologists, a large

[1] Willis, Bailey, Stratigraphy and Structure, Lewis and Livingston Ranges, Montana, Bull. Geol. Soc. of Am. vol. XIII, 1902, pp. 305—352.

district extending from New Mexico to eastern Wyoming was not submerged during the middle Paleozoic periods; but the absence of strata there may also be explained as the result of erosion in the Carboniferous. There was a general emergence at or near the close of the Mississippian period, and, after that, the sea was less widespread.

Beginning in Colorado and Dakota in the Pennsylvanian and becoming general in the Permian, land conditions seem to have prevailed. The characteristics of the Red Beds indicate sedimentation by intermittent streams and in salt lakes under an arid climate. Altho interrupted locally by a brief period of erosion accompanied in southwestern Colorado by mild folding at the close of the Permian, these conditions seem to have continued into the Jurassic. Later in the Jurassic period the northern part of the Rocky Mountain region, then a flat lowland, was invaded by a shallow gulf from the north, which brought with it a marine fauna allied to that of Alaska and the Arctic regions. Before the close of the Jurassic period, the sea withdrew from this broad depression and in it there continued to be deposited sediments of fresh water origin. The characteristics of these deposits are such as to indicate that the latest Jurassic and Comanchean beds were deposited by rivers and lakes on low plains. In the Cretaceous period the great mediterranean sea on the east advanced and temporarily covered most of the Rocky Mountain region. In the western part of the district, however, the land mass continued to be bordered by swampy shore plains as indicated by the coal bearing deposits of Utah and Western Colorado. Later in the Cretaceous period the sea receded completely, its final retreat being accompanied by the expansion of coastal river plains represented by the Laramie formation. At the close of the Cretaceous, or very early in the Eocene[1], there followed the deformativ movements to which the Rocky Mountains owe most of their present structure. The folding was spread over a wide area but was generally mild. It was accompanied by the intrusion of many small bodies of igneous rocks and the building of many scattered volcanic cones thruout the Rocky Mountain region. This has been called the "Laramide revolution".[2]

That the epoch of disturbance was followed by one of comparativ quiet, permitting the truncation of the folds, is shown by the fact that Eocene beds generally lie

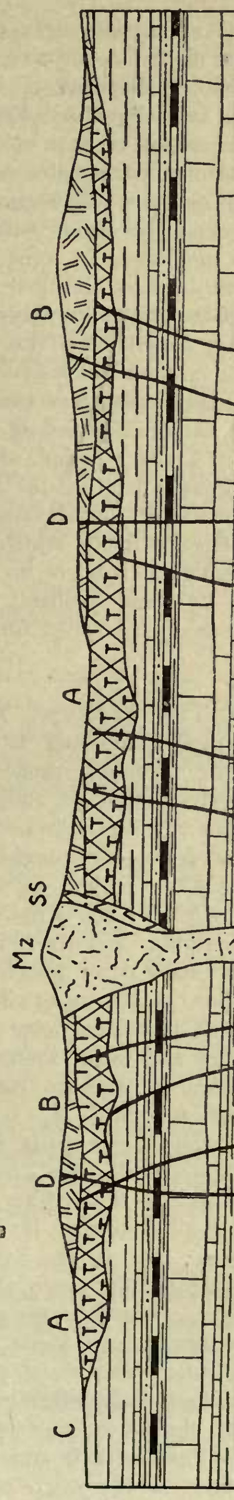

Fig. 35. Profile of a deeply eroded Tertiary volcano in the Highwood Mts. of central Montana: C, Cretaceous shale resting upon older Mesozoic and Paleozoic sediments; A, andesitic flows and breccia; B, basaltic flows and breccia; D, dikes; Mz, intrusiv monzonite; Ss, sodalite-syenite. (After W. H. Weed and L. V. Pirsson, U. S. Geol. Surv.)

[1] There is evidence to show that the deformation of the Rocky Mountains system involved at least two distinct episodes of folding, one at the close of the Cretaceous period and the other after the deposition of the Fort Union (Paleocene) beds of Montana. In general the former of these seems to have been the more pronounced, but in Montana and New Mexico, at least, the post-Paleocene upturning was the more important.

[2] Dawson, G. M., Geological Record of the Rocky Mountain Region in Canada, Bull. Geol. Soc. of Am., vol. XII, 1901, pp. 87—89.

upon the eroded edges of older rocks. The unevenness of the pre-Eocene surface in many districts, however, is proof that the region was not left in the condition of a peneplain. Deposits of volcanic ash in many of the Eocene formations and the lava flows in Yellowstone Park, indicate that eruptions continued into the Eocene. The region seems to have stood at a much lower elevation than now and to have enjoyed a warm moist climate, permitting the growth of palms and many plants and animals now indicativ of warm regions. Sometime within the Tertiary,—probably in the Miocene,—the region suffered very gentle folding or warping which has left the Eocene beds undulating in some places but nearly horizontal in others. This mild disturbance seems to have resulted generally in the deposition of coarser materials in the low grounds and to have been accompanied by a renewal of volcanic activity thruout the Rocky Mountains. The eruptions were especially prolonged and numerous in the region around Yellowstone Park. At the same time the northwestern edge of the Rocky mountain region was overwhelmed by the great flows of Columbia River basalt.

Another period of comparativ quiet seems to have intervened in the later part of the Tertiary period. Erosion was the chief activity and the result was the planation of broad areas in the Rocky Mountains. There is evidence of a drier climate and somewhat greater elevation at this time than in the Eocene. The Tertiary was closed by renewed uplifts which have continued at intervals thru the Quaternary, causing the present great relief of the mountain region. During the Quaternary period there were at least two and probably three epochs of glaciation in the mountains, and there is additional evidence of important climatic changes.

Physiography.

Topography. The topography of the Rocky Mountain tract is as diverse as are the climate and underground structure. Much of the region is characterized by isolated mountain ranges separated by wide flat-bottomed valleys or basins. The general trend of the ranges is north-south, but in the central region there are westerly and northwesterly trends. In central Colorado a view from any high point shows a sea of peaks and ranges rising one after the other into the dim distance. The peaks are not as rugged as those of many alpine mountains, but above tree-line (about 3000—3200 meters) the summits are covered with broken rock and have been hollowed into cirques. The rivers which enter and pass thru many of the interior basins leave them again thru narrow gorges; the valley of the Arkansas in Colorado is an example. The isolation of the mountain ranges and the breadth and flatness of the plains (bolsons), is most prominent near the southern end of the Rocky Mountains, where the ranges are low and much wasted. On the other hand, in the northwestern part of the Rocky Mountains, there are many rugged parallel ranges densely forested and separated by narrow valleys.

Physiographic History. Since nearly all of the region was the site of sedimentation during the Cretaceous period, the present topography must be of later origin. It is due to the erosion of rocks of varying degrees of resistance, standing in diverse structural attitudes. It is not due in any noteworthy measure to recent faulting or warping, nor to the building of volcanic cones. Under the influence of the relativly dry climate, the open anticlines and synclines have been etched in a characteristic manner. The outcrops of granitic rocks within the anticlines are generally markt by high mountains. Along the slopes of these mountain masses, the harder up-turned sedimentary beds stand out in relief as "hog-back" ridges, with parallel valleys between. The Black Hills afford well known examples. In the northwest there are important ranges due to the outcropping of massiv resistant beds in folds.

The detailed and comprehensiv physiographic studies necessary to an understanding of the origin and history of Rocky Mountain topography have not yet been

made. From an increasing number of investigations, however, it is becoming evident that a widespread upland surface may be recognized in many places. This has in turn been intrenched by one or perhaps two generations of valleys. In the higher ranges, the heads of these canyons have been further sculptured by glaciers. The upland surface is in some places that of a nearly base-levelled region, but elsewhere of a maturely mountainous country. Examples of the former condition are to be found in eastern Wyoming, and of the later in much of Colorado and northern Utah. Even the age of this upland is uncertain. It is referred to the Pliocene by Ball[1] and doubtfully to the late Tertiary by Blackwelder.[2]

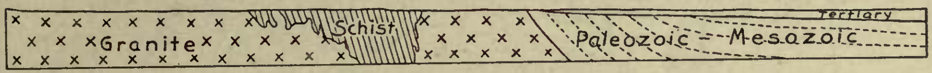

Fig. 36. Profile of the Laramie Mountains west of Cheyenne, Wyoming, showing the planation of the older rocks. (U. S. Geol. Surv.)

Of the valleys which have been incised into the upland, the upper reaches of some are wide and flat, while the lower courses are deep canyons. Such conditions suggest two cycles of valley development. In the higher mountains the deposits of the later glacial epoch lie within these canyons, but where the older glacial drift is found, the canyons have been cut thru old moraines and 100—300 meters down into the solid rock. It is therefore believed that the newer canyons are middle Pleistocene, while the more open shallow valleys are older.

The valleys which have been occupied by glaciers have been changed in the usual manner. Those that are strongly ice-worn have deep cirques at their heads and are well rounded in their lower courses, projecting spurs having been worn off and tributaries left hanging. Some of the divides between have been reduced to arêtes and the thick masses of glacial drift impound many lakes in the bottoms of the valleys.

Seismicity.

The Rocky Mountain region has been seismically quiet during historic times, for, since white men settled the country, not more than 100 years ago, no destructiv earthquakes have been recorded. Tremors and small seismic shocks have been reported from various parts of the region at somewhat infrequent intervals. In that respect it is comparable to the Interior Lowlands.

Colorado Plateaus.

General.

The broad plateau region between the Rocky Mountains and the Pacific Ranges is not readily divided, and such divisions as can be made intergrade with each other, making definit boundaries impracticable. Nevertheless there are certain real and conspicuous differences which make it seem advisable to separate the plateau country into three parts, — essentially those suggested by J. W. Powell.

The Colorado plateaus include parts of Arizona, Utah, and western New Mexico. They are high table-lands, underlain chiefly by Paleozoic and Mesozoic rocks, with which are associated Tertiary lavas and a veneer of later sediments. The table-lands have been broken by faults which have produced a series of steps. Locally they

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[1] Spurr, J. E., Garrey, G. H., and Ball, S. H., Geology of the Georgetown Quadrangle, Colorado. U. S. Geol. Survey, Prof. Paper 63, 1908.

[2] Blackwelder, E., Cenozoic History of the Laramie Region, Wyoming. Jour. of Geol., vol. XVII, 1909, p. 437.

have also been domed by laccolithic intrusions, and a few volcanic cones rise above their surface. The plateaus are trencht by some of the deepest canyons in the world,—those of the Colorado river and its tributaries. Being subject to an arid climate the plateaus furnish conditions for forests only on the higher mountains.

Stratigraphy.

In general the stratigraphy of the Colorado plateaus is much like that of the Rocky Mountains, except that the Mesozoic rocks are less well displayed and the Tertiary record is even more deficient.

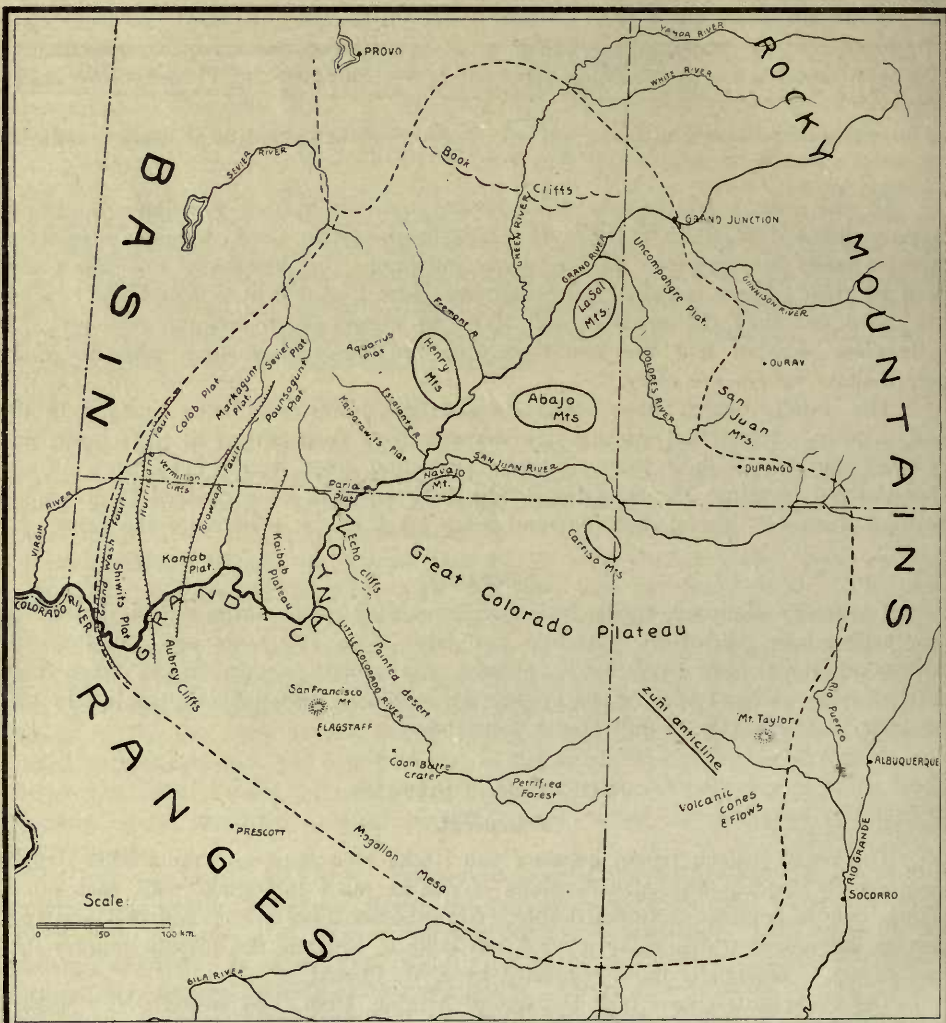
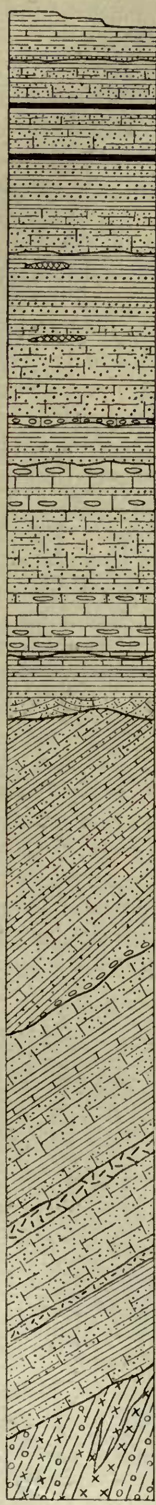


Fig. 37. Sketch map of the Colorado plateau.

At the base of the section there is a metamorphic series generally referred to the Archeozoic, but probably including some Proterozoic rocks. Gneisses, greenstone-schists, rhyolites and other meta-igneous rocks predominate. Granites and related igneous rocks have been intruded into them.

A late Proterozoic series of quartzite and slate with a few interbedded lava flows corresponds to the similar formations in the Rocky Mountains. Here also a few traces



Per.	Div.	Formation.	M.	Description.
Eocene.	Lower.		240+	Non-marine marl and shale, with sandstone and limestone.
		Unconformity.		
Cretaceous.			943	Soft, more or less calcareous sandstone and dark argillaceous and carbonaceous shale, with beds of coal; mainly marine, in part non-marine.
		Unconformity.		
Jurassic ?		Painted Desert.	300±	Bright red calcareous and gypsiferous shale, with some sandstone. Underlain by massiv white sandstone.
Triassic.		Leroux.	500±	Red and buff sandstone, with beds of shale and gypsum (petrified logs).
		Shinarump.	20±	Conglomerate with petrified wood.
		Unconformity.		
Permian.		Moencopie.	200	Laminated red and brown, gypsiferous, arenaceous shale, sandstone and marl. (No fossils.)
		Unconformity.		
Pennsylvanian.	Aubrey group.	Kaibab.	240±	Massiv, cherty limestone with an arenaceous gypsiferous bed. *(Productus ivesi, P. semirecticulatus, Pugnax utah?).*
			100	Friable gray sandstone.
		Coconino.	300±	Friable, reddish sandstone, with thin beds of limestone below.
Mississippian.		Red Wall.	275±	Arenaceous and cherty limestone above *(Spirifer cameratus, Productus nebraskensis,* etc. above) with massiv gray limestone and chert below. *(Spirifer centronatus,* etc.)
Devonian.		Temple Butte.	0—30	Impure purplish limestone and yellow sandstone.
		Unconformity.		
Cambrian.	Middle. Upper.	Tonto.	320±	Greenish shale with beds of limestone above, and sandstone below. *(Bathyurus, Conocoryphe,* etc. below; *Dikelocephalus* above).
		Angular unconf.		
Proterozoic (Algonkian).	Upper ?	Chuar.	1560	Sandy gray shale and sandstone, with thin beds of limestone (obscure fossils.)
		Unconformity.		
		Unkar.	2040	Gray, brown and purple sandstone and shale, with interbedded lava flows and a little limestone.
		Angular unconf.		
Archean.		Vishnu.	?	Schist and gneiss, with dikes of granite.

GENERALIZED SECTION OF STRATA IN THE GRAND CANYON REGION, ARIZONA.[1]

[1] Compiled from writings of C. D. Walcott, C. E. Dutton, E. Huntington, N. H. Darton, and others, 1880—1910.

of fossils of doubtful origin have been found, and much of the series appears to be non-marine.

The Paleozoic sequence is rather thin and variable. It comprises middle and upper Cambrian at the base, generally overlain by Devonian and Carboniferous limestones. Limestones of Ordovician and Silurian age have been recognized in southwestern New Mexico. Obscure unconformities interrupt the sequence as in the Rocky Mountains, and in northwestern New Mexico all the pre-Carboniferous terranes disappear.

The Mississipian and Pennsylvanian systems are represented chiefly by limestone, but on the southeast border of the element there is much shale and sandstone and even a few coal seams.

The Carboniferous limestones pass upward into the red beds of Permo-Triassic age. In contrast to the Rocky Mountains there appears to be within this sequence an unconformity corresponding approximately to the close of the Permian period.

Altho on the average thinner, the Mesozoic rocks are much the same in the plateaus as in the Rocky Mountains, except that the Jurassic beds are largely non-marine. In the Kolob sandstone, apparently of that age, the bedding is intricately festooned and the formation is thought to be eolian in origin.

Except on the southern border of the plateau region, the Comanchean system is absent and the upper Cretaceous rests unconformably upon Jurassic or occasionally on older beds. The Cretaceous is here a coal-bearing system of shales and sandstones, in general like that of the western side of the Rocky Mountains.

Altho the Tertiary sediments are generally unconformable upon the older rocks the unconformity is much less conspicuous in the plateau region because the Paleozoic strata themselves have been but little folded.

The Tertiary systems are represented chiefly by lacustrin and fluviatil marls or clays of the Eocene. At the base lies the Puerco-Torrejon series, which contains two of the oldest known Tertiary faunas (Paleocene), probably partly homotaxial with the Ft. Union of Montana. The late Tertiary deposits have yielded but few fossils and are imperfectly known. There are rhyolitic lavas of early Tertiary age, together with intrusions and outpourings of Miocene volcanic rocks, among which andesite, trachite and basalt are common. Except on a few of the highest mountains there are no glacial deposits. The Quaternary sediments, which cover the bottoms of the more open valleys consist therefore of fluviatil sand and gravel and dune sand.

Structure.

As in the Rocky Mountain region, the oldest rocks of the Colorado Plateaus have been intensely folded, metamorphosed and traversed by many intrusions. In the best known region, the Grand Canyon of the Colorado, the late Proterozoic beds are only gently tilted and broken by a few normal faults. In short, their structure is much like that of the overlying Paleozoic beds.

The entire Paleozoic and Mesozoic sequence is a unit structurally, altho divided by several obscure unconformities. It is not as much folded here as in the Rocky Mountains, but its deformation has been effected largely by faulting. Powell's classic diagrams long since showed that the structure of the plateaus involves thick horizontal beds in which there are monoclinal flexures and step-like faults; and more recently it has been found that the latter are of two or even three distinct ages. The faults are all nearly vertical and are of the type generally called normal.

Of igneous structures there is much variety in the plateau region. Here and there upon the plateaus there are volcanic cones,—some recent and scarcely marred by erosion, while others are so old that only the hard igneous rocks in the throats of the volcanos remain as isolated buttes. In southern Utah are the Henry Mountains, caused

by the group of blister-like intrusions to which Gilbert first applied the name "laccolith". There are other laccoliths scattered over the plateau country. Many dikes are associated with both the volcanic necks and the laccoliths.

Geologic History.

The history of the Colorado plateau is in general much like that of the adjoining Rocky Mountains; and yet there are important differences between the two.

The sediments which now form the Grand Canyon system began to be deposited presumably in later Algonkian time on the surface of a deeply eroded mass of schistose rocks. There are reasons for thinking that the sediments were deposited chiefly on aggraded plains rather than in the sea. The implications of the few interbedded lava flows and the obscure unconformity midway in the sequence are obvious. After the sediments ceast to be deposited they were consolidated, gently flext and here and there broken by normal faults. Subsequent erosion went so far as to remove the fault scarps entirely and to reduce the region to low relief.[1]

This eroded surface was slowly covered by an encroaching sea in or near which were deposited the Tonto sandstone and shale in middle or late Cambrian time. There is evidence that the sea withdrew at one or more times in the middle of the Paleozoic era, for the Ordovician and Silurian rocks are generally absent and the thin Devonian limestone is bounded below and above by obscure unconformities except in the southeastern part of the province.

Thru most of the Paleozoic era, however, and especially the later portion, the conditions were probably such as to permit the deposition of marine limestone in much of the region. Slowly, toward the close of the Paleozoic, the marine conditions gave way to those of a land surface with a climate which must have been arid.

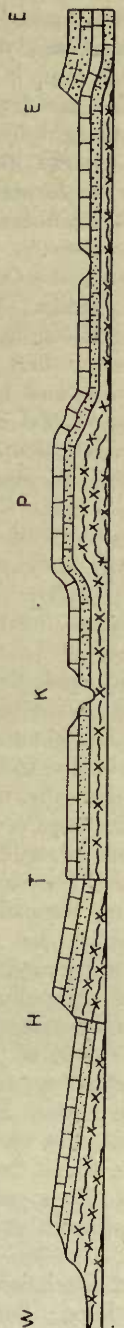


Fig. 38. Stereographic profile of the Colorado Plateau north of the Colorado canyon in northern Arizona: H, Hurricane fault; T, Toroweap fault; K, Kanab canyon; P, Kaibab plateau; E, Echo cliffs. (After J. W. Powell.) Length about 225 km.

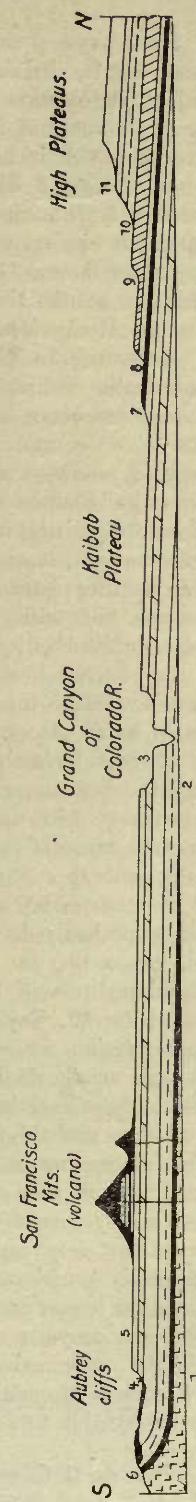


Fig. 39. Profile of the Colorado Plateau in northwestern Arizona. About 215 km. long. (After G. K. Gilbert.)

[1] L. F. Noble, Contributions to the geology of the Grand Canyon, Arizona, Am. Jour. Sci., 4th Ser. vol. XXIX, 1910, pp. 497—528.

Some physical change then permitted the widespread but not deep erosion of the Permian strata, before those usually referred to the Triassic were laid down. The Triassic conglomerate with overlying red sandstone apparently marks the continuation of the dry climate of the Permian, and yet the bones of reptils and local accumulations of petrified wood, including huge logs, in the Shinarump formation show that the land was not entirely a desert. The wonderfully crossbedded pure white sandstone probably of early Jurassic age is thought by W. M. Davis to be of eolian origin. If the interpretation is correct, the plateau region may have been a Sahara covered with drifting sand dunes. Later in the Jurassic period the northern end of the region was invaded for a brief time by the southern end of the Logan sea which also overspread part of the Rocky Mountain province.

According to W. Lindgren, the Cretaceous rocks of New Mexico are generally unconformable on all the older strata. The contrast between the entire Comanchean-Cretaceous sequence of sediments on the one hand and the Permo-Jurassic sequence on the other cannot fail to show that conditions had radically changed. The dark shales and yellow sandstones with coal beds and plant fossils seem to denote alluviation on swampy plains,—doubtless coastal lowlands bordering the great interior sea. At times, especially in the middle Comanchean, a part of the region was submerged beneath the sea, leaving a deposit of marine shale and limestone. At the close of the Cretaceous the plateau region like the Rocky Mountains was subjected to deformativ influences, but with much less prominent effects. Over considerable areas the strata still lie undisturbed, but locally they were bent down in the form of monoclines or were sharply broken along faults. These structures seem to have been truncated by erosion before the deposition of the Eocene beds, altho the evidence of this is not available in all places.

It was formerly thought that the plateau region was occupied by vast lakes during the Eocene period, but it is now recognized that much of the Eocene series was probably laid down by aggrading streams in broad flat-bottomed valleys. That there were lakes of considerable size is, however, attested by the fish-bearing limestones. Volcanic activity continued sporadically.

In the midst of the Tertiary period there came an epoch of mild disturbance which is probably to be correlated with other events of its kind thruout the western states. According to Leith and Harder[1], the Iron Springs laccoliths of Utah, and presumably those of the Henry Mountains, were intruded at this time; the volcanic necks of the Mt. Taylor region perhaps represent sympathetic eruptions. At the same time the region was slightly warpt and the older generation of faults is believed to have been made at this time. According to Dutton the entire region had been worn almost to base-level before the volcanic eruptions of this epoch took place.

Later, probably near the close of the Tertiary period, there was a renewal of the uplifts, amounting to 1000 meters or more, with further dislocations along the fault planes. About the same time, also, basalt was again erupted in many places and spread widely over the surface. The rivers, rejuvenated by these disturbances, thereafter cut the deep canyons for which the region is renowned. This was accompanied by successiv eruptions of basic lavas,—some of them recent, for here and there fresh black cinder cones are scattered about over the plateaus, and flows have run down into the deepest canyons.

The only evidences of glaciation are found on the highest peaks, such as San Francisco Mountain in Arizona; but in the sediments upon the plateaus it may soon be possible to read the record of important climatic oscillations.

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[1] Leith, C. K., and Harder, E. C., The Iron Ores of the Iron Springs district, southern Utah. U. S. Geol. Survey, Bull. 338, 1908.

Physiography.

To students of physiography the plateau region has been one of the most important, for it was the scene of the fruitful labors of such men as Powell, Gilbert and Dutton, whose lucid interpretations of land forms and processes have added greatly to the advancement of the science.

Topography. The Colorado plateaus are a series of table lands, 2000 meters or more in height, separated by cliff scarps or abrupt flexures and surmounted by fresh or partly demolished volcanic cones and isolated mountain groups of laccolithic origin. The plateaus are deeply trencht by the Colorado River and its many tributaries. The well named Grand Canyon of the Colorado is 1000 to 1800 meters deep and, ever since the early explorations, of which that by Powell was the most daring and fruitful, it has been well known as one of the wonders of the world. The river has cut down thru a thick series of Paleozoic rocks far into the mass of Archean granite and schist beneath. The stream is still high above grade and is engaged in removing rapids and falls from its channel.

The peculiar details of the topography are due in large measure to the arid climate which in turn spells lack of vegetation. This leaves the rocks bare and gives the wind and torrential rains free scope for their work. It is true that the highest plateaus and peaks receive as much as 20 inches of rainfall a year and are clad with forests; but such areas are not large. The land forms are due to the unequal resistance of horizontal beds of rock exposed to incessant wind action and scoured by occasional altho violent torrents. At the edges of the plateaus and canyons jagged cliffs with pinnacles and an infinit variety of grotesque forms are characteristic.

By the constant undermining, the plateaus and mesas decrease in size and are dismembered into isolated hills or "buttes". Some of the escarpments, due to comparativly recent faulting, may be known by their straight courses, presenting continuous walls gasht by short ravines. Hurricane Ledge is perhaps the best known of these scarps.

No description of the topography of the plateau region would be complete without mention of the remarkable coloring, which is due partly to the original variety of white, red, pink and gray sediments and partly to the absence of a covering of vegetation which would otherwise obscure them. Some hint as to the intensity of these colors may be drawn from such names as "Painted Desert", "Flaming Gorge", and others equally suggestiv.

Physiographic History. In general it may be said that the topography of the plateau region is all post-Cretaceous, as in the Rocky Mountains. Even during the Eocene period much of the region was subject to sedimentation, and in the Miocene large areas were buried beneath lava sheets, so that most of the present topography must be post-Miocene. According to Huntington and Goldthwaite[1], the general surface of the plateaus represents the Mohave peneplain, of which further mention will be made in the next chapter (p. 161). This surface has the aspects of topographic old age in the south and west, but becomes somewhat more hilly and mature north and eastward. The age of this surface is not definitly determined, but the weight of evidence indicates that it is late Miocene or Pliocene. Upon this plain much volcanic matter was ejected. Whatever its age, the peneplain was at a later time raised somewhat differentially but on the average 1000—2000 meters, and at the same time tilted slightly toward the north and northeast. The later generation of faults, producing existing scarps, seems to have been associated with this uplift. Robinson[2]

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[1] The Hurricane Fault in the Toquerville district, Utah. Harv. Coll. Mus. Comp. Zool., Bull. 42, 1904, pp. 199—259.

[2] Robinson, H. H., A New Erosion Cycle in the Grand Canyon District, Arizona, Jour. of Geol., vol. XVIII, 1910, pp. 742—763.

has recently shown that there were in reality two periods of uplift, one at the beginning of the Quaternary period and another near the middle of the same period, separated by a long erosion interval. By causing the rejuvenation of the drainage systems the great uplift initiated the cycle of canyon cutting, which is still in vigorous youth. Deep trenches have been cut in the plateaus, the limiting fault escarpments have been gasht and most of them have receded somewhat from the original lines of dislocation.

As important incidents in the physiographic development of the region, mention must be made of the large and small volcanic cones,—some of them mere heaps of cinders,—which have been built upon the surface of the plateau in comparativly recent times. A few of the lava flows have cascaded down the sides of the modern canyons, and must therefore be very young.

Seismicity.

Like the Rocky Mountain region the plateau country seems to be at present in a condition of relativ stability. In spite of the fact that there is good evidence of faulting in rather recent times, geologically speaking, there are no records of destructiv earthquakes within the past century or more. Mild earthquake shocks, a few of which have cracked the walls of houses have been felt at Socorro, N. Mex., near the southeast edge of the province, and Bagg[1] correlates these with modern faults in the vicinity.

Basin Ranges Element.

General.

The central and southwestern portion of the broad region between the Rocky Mountains and the Pacific Mountains differs in some essential respects from the Colorado plateaus. A series of parallel north and south ranges rises above a surface which has an average elevation of 1200 to 2000 meters, altho it sinks to sea level or lower along its southwestern border. The ranges are somewhat lower than those of the Rocky Mountains and the Sierra Nevada and are generally separated by flat bottomed desert valleys. In these arid wastes the mountain streams disappear in the sands or in some places empty into saline lakes. In the entire region there is but one stream, the Colorado River, which succeeds in reaching the sea.

Rocks of nearly all ages may be found in this province, but the Paleozoic terranes make the foundation in most places. Mesozoic rocks are generally absent. Where present, in the southwestern portion, they are much like those of the Colorado plateaus; while in the northwestern part the Jurassic and Triassic systems are represented by the marine Pacific phase. All over the district there are vast quantities of Tertiary volcanic rocks with partly denuded Tertiary and older igneous intrusions.

The pre-Cretaceous rocks are much folded along the western side of the Basin Ranges but less so in the central and eastern portions. The western part was severely affected by the post-Jurassic orogeny, while the eastern part was deformed rather at the close of the Cretaceous. The distinctiv character of the present Basin ranges has been supposed to be due to many parallel normal faults of comparativly recent date, the scarps having been modified and the valleys partly filled under the peculiar conditions of erosion and deposition incident to an arid climate. More recently this opinion has been vigorously attackt.

The limits of the province are of course somewhat arbitrary and indefinit. The Wasatch Range of Utah and its continuations north and south, are generally regarded

[1] Bagg, R. M., Earthquakes in Socorro, New Mexico, Am. Geol. XXXIV, 1904, pp. 102—104.

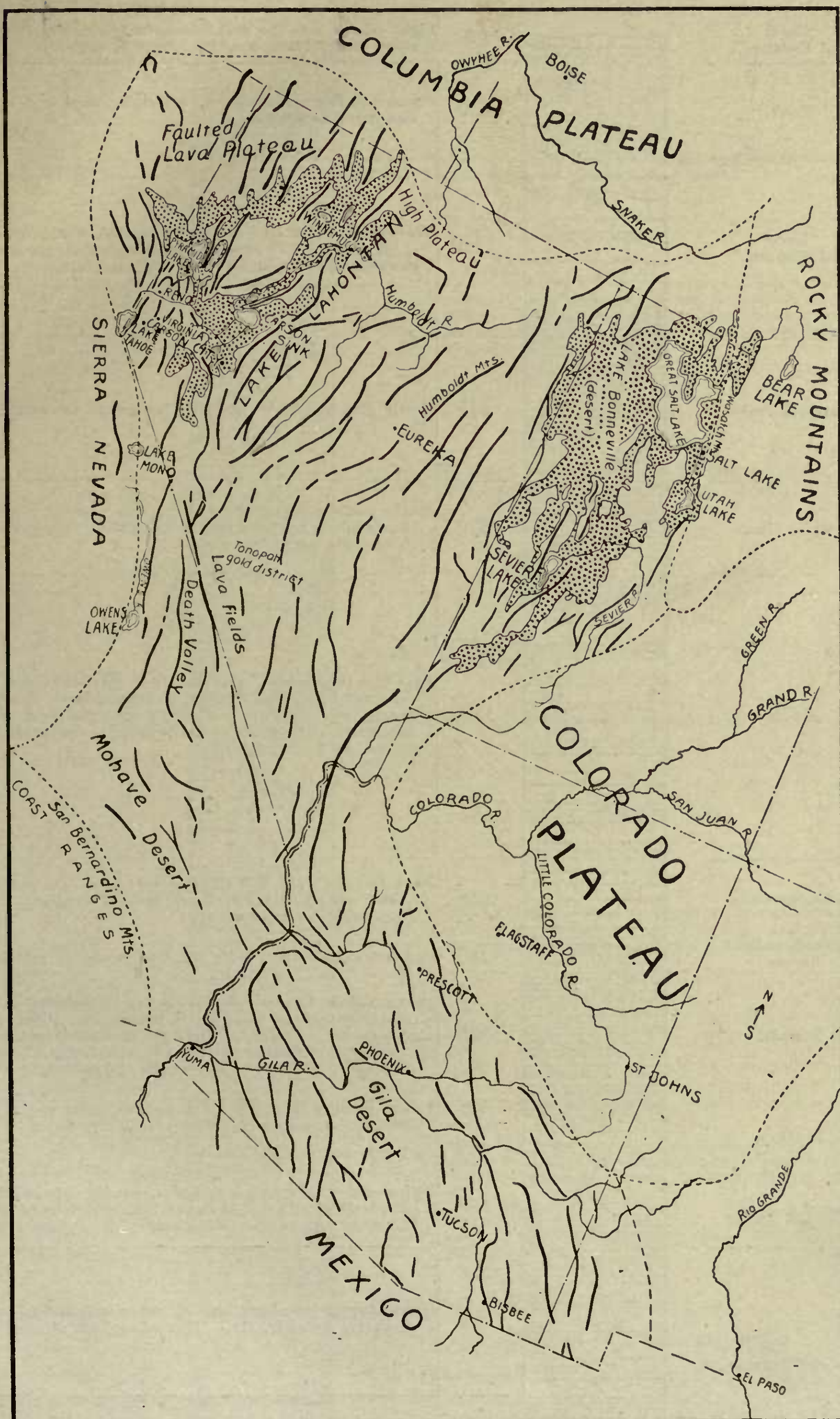
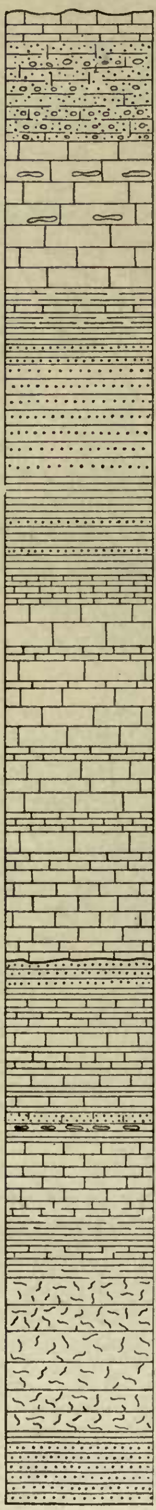
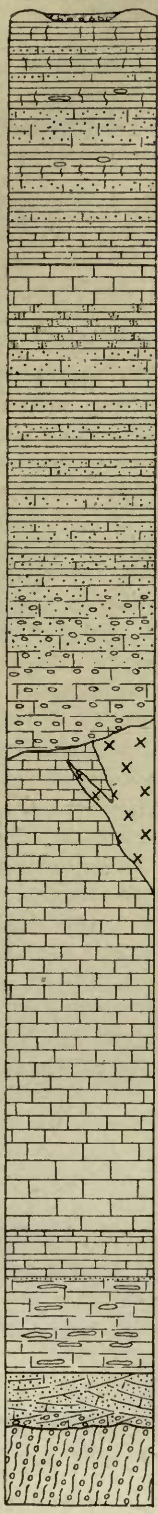


Fig. 40. Sketch map of the Basin Ranges Element.

Per.	Div.	Formation.	Strata.	M.	Description.
Pennsylvanian.		"Upper Coal Measures".		150	Light colored blue and drab limestones (*Fusulina, Productus, Spirifer, Spiriferina, Myalina, Athyris,* etc.).
		Weber.		610	Coarse and fine conglomerates, containing chert and layers of reddish-yellow sandstone.
		"Lower Coal Measures."		1120	Heavy bedded dark blue and gray limestone, with intercalated bands of chert (*Chonetes granulifera, Productus costatus, Spirifer cameratus,* etc.); argillaceous beds near base.
Mississippian.		Diamond Peak.		915	Massiv gray and brown quartzite, with shale at summit.
- ? -		White Pine.		610	Black, sometimes arenaceous shale, with beds of friable sandstone (*Bellerophon neleus, Spirifer disjunctus, Spiriferina cristata, Paracyclas peroccidens,* etc.).
Devonian.		Nevada.		1780	Massiv to thin-bedded, gray to black limestone. (In upper part: *Bellerophon maera, Mytilarea chemungensis, Cyrtina hamiltonensis,* etc. In lower part: *Platyceras nodosum, Conocardium nevadense, Atrypa reticularis, Spirifer varicosus, Orthis impressa,* etc.).
Silurian. ?		Lone Mountain.		550	Black to gray, dense and siliceous limestone. (In upper part: *Halysites catenularia.* In lower part: *Trinucleus concentricus, Plectambonites sericeus,* etc.).
Ordovician.		— Unconformity. — Eureka.		150	Compact and vitreous, white and blue quartzite; reddish near base.
		Pogonip.		825	Interstratified fine-grained, bluish-gray limestones and argillites; arenaceous beds at base; highly fossiliferous. (Upper portion: *Receptaculites, McClurea, Dalmanella testudinaria, Endoceras proteiforme, Illaenus crassicauda,* etc. Lower portion: *Agnostus communis, Illaenurus Eurekensis, Strophomena nemea,* etc.).
Cambrian.	Upper.	Hamburg.		105	Yellow shale with many chert nodules, especially near the top. (*Obolella, Agnostus, Dikellocephalus, Ptychoparia,* etc.).
				365	Dark gray and granular limestone.
		Secret Canyon.		490	Yellow and gray argillaceous shales, passing into shaly limestone; interstratified layers of shale and thin-bedded limestones near top (*Acrothele, Kutorgina, Dikellocephalus, Agraulos,* etc.).
	Middle.	Prospect Mountain.		930	Gray, compact limestone, bedding planes imperfect (*Agnostus, Ptychoparia, Secnella,* etc.). (*Olenellus* fauna at base).
	Lower.			460+	Bedded brownish-white quartzite; layers of arenaceous shale; fossils in shale near top (*Olenellus, Anomocare,* etc.).

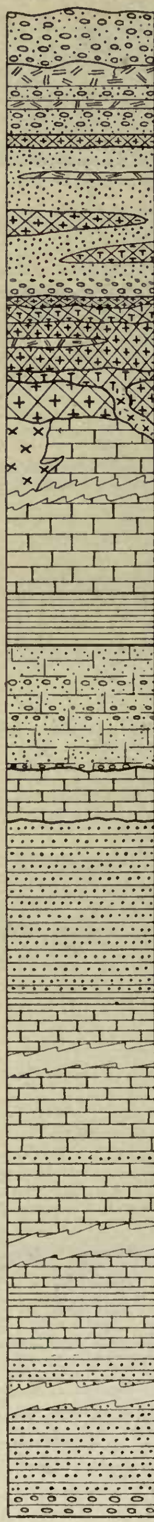
SECTION IN NORTHERN NEVADA.[1]

[1] Near Eureka, after A. Hague and C. D. Walcott, U. S. Geol. Survey, 1884.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.					Gravel and sand.
Comanchean (Lower Cretaceous).		Centura.		550+	Red nodular shale with cross-bedded buff, tawny, and red sandstone; beds of impure limestone near base.
		Mural.		200	Limestone, thick-bedded, hard, and fossiliferous above (*Ostrea, Orbitolina texana, Caprina occidentalis,* etc.), and thin-bedded, arenaceous, and fossiliferous below (*Pecten slantoni, Ostrea, Trigonia stolleyi,* etc.).
		Morita.		550—600+	Buff, tawny, and red sandstones and dark red shales, with occasional thin beds of impure limestone near the top.
		Glance.		8—760	Bedded conglomerate; pebbles angular and chiefly of schist and limestone.
					Granite and granite-porphyry intrusions.
		Unconformity.			
Pennsylvanian.		Naco.		900+	Chiefly light gray, compact limestone; fossils abundant (*Fusulina cylindrica, Derbya crassa, Productus nebraskensis, Spirifer cameratus, Hustedia mormoni, Seminula subtilita,* etc.).
Mississippian.		Escabrosa.		200	Thick-bedded white and light-gray limestone, with abundant crinoid stems. (*Chonetes loganensis, Spirifer centronatus, Athyris lamellosa, Eumetria marcyi, Myalina keokuk, Phillipsia peroccidens*).
Devonian.	Upper.	Martin.		100	Dark gray, fossiliferous limestone (*Atrypa reticularis, Spirifer hungerfordi, S. Whitneyi, Schizophoria striatula, Acervularia davidsoni*).
		Unconformity.			
Cambrian.	Middle.	Abrigo.		235	Thin-bedded, impure, cherty limestone.
		Bolsa.		130	Cross-bedded quartzite, with basal conglomerate.
		Unconformity.			
Pre-Cambrian.		Pinal.		?	Sericitic schist.

SECTION IN THE BISBEE DISTRICT, SOUTHEASTERN ARIZONA.[1]

[1] After F. L. Ransome, U. S. Geol. Survey, 1904.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.	Pleistocene and Recent.			120+	Desert gravel and dnne sand.
		Unconformity.		?	Basalt.
				?	Older altnvium.
				?	Basalt.
				?	Older allnvium, with Pliocene lake (?) beds at base.
Pliocene (?).		Unconformity.		?	Rhyolite.
		Siebert.		350	Lake beds with rhyolite, dacite, and basalt flows.
Miocene.		Unconformity.		?	Rhyolite.
				?	Basic andesite and dacite.
				?	Rhyolite, with minor basalt flows.
Eocene.		Unconformity. Unconformity.		?	Acid andesite and intrusiv monzonite porphyry.
				?	First rhyolite.
Jurassic (?).	Late.	Unconformity. Intrusions.			Intrusiv granite and diorito.
Pennsylvanian.				760	Dark, dense limestone.
				90—150	Green and gray shale.
		Weber.		245—305	Sandstone and conglomerate.
Silurian.		Unconformity. Lone Mountain.		120+	Dense, gray limestone.
Ordovician.		Unconformity. Eureka.		360—460	Pure white to pink quartzite.
		Pogonip.		600—1200	Massiv, dense, gray limestone with one bed of quartzite.
Cambrian.		Prospect Mountain.		1500—1800	Dark dense limestone and green shale.
				600—900	Quartzite, with conglomerate below and shale above.

FORMATIONS IN SOUTHWESTERN NEVADA AND SOUTHEASTERN CALIFORNIA.[1]

[1] Modified after S. H. Ball, U. S. Geol. Survey, 1905.

as the eastern boundary, while the Sierra-Cascade system hems in the region on the west. The southeastern part is in reality a northward prolongation of the western Sierra Madre province of Mexico and differs in some respects from the rest of the Basin Ranges. Northward the distinctiv structures of the element are buried beneath the lavas of the Columbia Plateau.

Stratigraphy.

General. The rocks of the Basin Ranges represent nearly all ages from Archean to modern. The oldest terranes are not widely exposed nor as yet well understood. They are believed to be partly Archeozoic and partly Proterozoic. The prevailing rocks are limestones, quartzites and shales of Paleozoic age associated with vast quantities of much younger intrusiv and extrusiv igneous rocks. The ranges are swathed in more recent Tertiary and Quaternary deposits.

Ancient Schistose Formations. Here and there beneath the unaltered Paleozoic sediments there are ancient gneisses, schists, and granitic intrusivs. In Utah these are clearly older than the late Proterozoic, and have been generally referred to the Archean. In Arizona and other southeastern districts the schistose terranes are also clearly pre-Cambrian, altho beside gneiss and granite they contain much sedimentary material and for that reason have been considered partly Algonkian. In the western part of the Basin Ranges, the correlation of the metamorphosed terranes is more difficult because of the intense post-Jurassic diatrophism. Some of the schistose and granitic formations, referred by earlier explorers to the Archean, have since been shown to be Triassic or Carboniferous. On the other hand some of the metamorphic rocks of the region are doubtless pre-Cambrian, for in the Snake Range of Nevada, F. B. Weeks found granitic rocks lying beneath metamorphic quartzite and slate, which in turn lie far below the sub-*Olenellus* fauna.

The Folded Sedimentary Series. The Basin Ranges are composed largely of tilted or moderately folded sedimentary rocks, becoming more highly deformed westward. These rocks are chiefly Paleozoic but in part older and in part younger. In northern Utah, a great quartzite-slate system like that of the Algonkian of the Wasatch Mountains lies at the base of the series. There is evidence that in southwestern Nevada rocks of coordinate age are present, more highly metamorphosed and disturbed. Generally thruout the Basin region, where the Algonkian is lacking, the lowest member of the series is the Lower Cambrian, characterized by the *Olenellus Gilberti* and still older faunas. This consists generally of quartzite, followed by shale which in turn passes up into a thick body of limestone with occasional intercalations of slate and quartzite. The limestones represent nearly all of the Paleozoic era. The Ordovician and Silurian systems consist generally of limestone, altho in northern Nevada there is quartzite of late Ordovician age. Above the Silurian limestone lies shale with another thick limestone formation. Both were formerly referred to the Devonian, but there is reason to believe that the upper part is of Mississippian age. The Eureka quartzite of Nevada, which appears to be middle Carboniferous, has not been widely recognized outside of the original district in Northern Nevada. The Pennsylvanian system generally consists of massiv limestone of gray colors. In northern Nevada there are local beds of quartzite and conglomerate within the limestone, and farther south other clastic formations replace the limestone. In southern Nevada Ball[1] found the Pennsylvanian system resting unconformably upon middle Paleozoic rocks, but such an interruption has not been found in most parts of the district. It appears that there are no Permian rocks in the central part of the Basin Ranges, but in western Nevada the

[1] Ball, S. H., A Geologic Reconnaissance in southwestern Nevada and Eastern California. U. S. Geol. Survey, Bull. 308, 1907.

metamorphic sedimentary formations probably include marine Permian of the Pacific type, while in Arizona the Red Bed phase of the Permian,—characteristic of the Rocky Mountain province,—extends over into the Basin Ranges from the east.

Mesozoic Systems. For Mesozoic rocks one must turn to the northwest and southeast parts of the Basin Ranges element. In western Nevada and adjacent parts of California there is a sequence of marine shales and limestones containing Triassic and Jurassic fossils of the Pacific region. They are intensely folded and cut by intrusions of granodiorite and other igneous rocks. Locally they are so much metamorphosed that they were first thought to be Archean. Comanchean and Cretaceous rocks have not been found there.

In southern Arizona the Triassic and Jurassic systems are generally absent but the Comanchean is fairly well developt. It consists of conglomerate and shale with a middle limestone containing a marine fauna of the Texas type. The beds rest unconformably upon a variety of older rocks. No outcrops of the upper Createaceous system have been found in the Basin Ranges, altho in northern Arizona and Utah they almost reach the border of that province.

Tertiary and Later Continental Deposits. The depressions between the Basin Ranges are filled with continental deposits of imperfectly known age. Altho there is a widespread veneer of Quaternary sand and gravel, the thicker underlying beds are generally Tertiary. These consist largely of fluvial gravel, sand and clay, with eolian sand and lacustrine deposits. Among the last there are not only stratified silts but many deposits of gypsum and calcareous tufa, with smaller beds of salt and borax. As these formations are generally devoid of fossils, but little is known as to their age. Their relations show that some are older and some younger, and it has been definitly determined that both Eocene and Miocene systems are represented.

Vast quantities of Tertiary volcanic rocks are spread over the Basin Ranges province. The stocks and dikes form prominent peaks in the ranges themselves, while the flows and deposits of breccia and ash generally occupy the lower slopes and intervening depressions. Altho the extrusivs are partly basaltic, this region is characterized by an abundance of acidic lavas such as andesite, dacite, and rhyolite. In age, the igneous rocks range thruout the Tertiary and into the Quaternary, altho perhaps the Miocene eruptivs are somewhat more abundant. Other intrusivs of post-Jurassic and some of pre-Cambrian age are not always easily distinguisht from them. In Arizona and Utah there are a few little cinder cones which are so fresh that it is evident they are very recent. The Basin Ranges province is deficient in glacial deposits. Only on a few of the highest peaks are there small local moraines.

Structure.

General. The Basin Ranges are so largely buried beneath alluvial deposits and superficial volcanic debris that even the larger structural features are partly concealed. The most ancient rocks, generally Archeozoic or perhaps early Proterozoic, are everywhere intensely folded and intruded by batholithic and other masses of igneous rocks. The prevailing sedimentary rocks of Paleozoic and early Mesozoic age are generally folded but not much metamorphosed.

The Pre-Cambrian Folded Strata. Generally thruout the Basin region the rocks are gently folded altho locally overturned. In many ranges igneous intrusions have reduced the sedimentary beds to mere fragments. They have a north-south trend in the central and northern part of the district but a northwesterly trend in the south and southeast. In addition volcanoes and dome-like extrusions of acidic lavas have been built upon the older structures.

The folds, intrusions, and extrusions are all intersected by faults. The few overthrusts which have been recognized are definitly related to the process of folding,

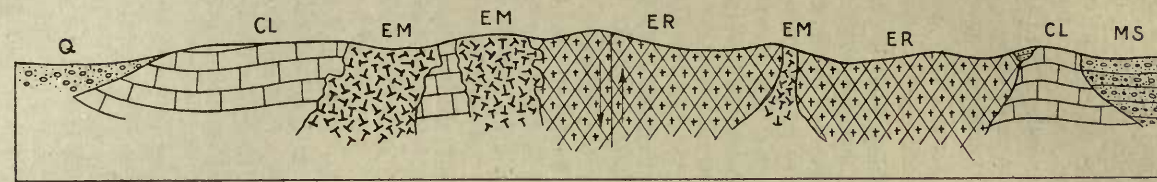


Fig. 41. Profile across Stone Wall Mountain, Nevada. (After S. H. Ball, U. S. Geol. Surv.) — Er, Eocene rhyolite; Em, Eocene monzonite-porphyry; Cl, Cambrian limestone; Ms, Miocene sediments. Length of profile, 9½ km.

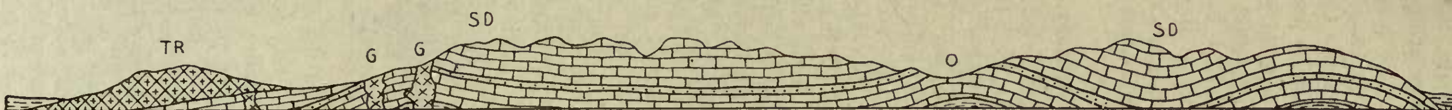


Fig. 42. Profile of the Quinn canyon and Grant Ranges, Nevada. (After J. E. Spurr, U. S. Geol. Surv.) — O, Ordovician limestone and shale; SD, Silurian and Devonian limestone and quartzite; G, granite dikes; Tr, Tertiary rhyolite. Length of profile, about 70 km.

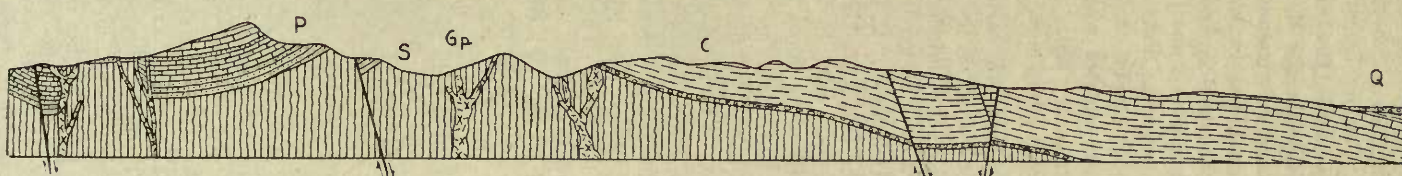


Fig. 43. Geologic profile near Bisbee, Arizona: P, Paleozoic quartzite and limestone [Cambrian to Carboniferous]; S, schistose rocks [Archean?]; Gp, intrusiv granite and porphyry in the form of dikes and stocks; C, Comanchean conglomerate, shale and limestone; Q, Quaternary gravel and sand (after F. L. Ransome, U. S. Geol. Surv.).

but the normal faults, which appear to be far more abundant, are probably of later age. In some localities, as at Tonopah, Nevada, the rocks are broken into a mosaic of angular blocks. In all cases these complex groups of faults appear to be associated genetically with Tertiary igneous intrusions.

Tertiary and Quaternary Deposits. Altho similar in origin to the homataxial deposits in the Rocky Mountains the Cenozoic beds of the Basin province have suffered more deformation. In the eastern part of the region they are generally but little disturbed, but in western Nevada and eastern California the older Tertiary beds have been moderately folded, broken by faults and intruded by igneous masses. Miocene beds and even some formations referred to the Pliocene have been upturned at angles of as much as 25°. In the vicinity of Death Valley in southeastern California beds of silt thought to be of early Pleistocene age are inclined as much as 15°. Many fresh fault scarps, some of which indicate a displacement of 1000 meters or more, are doubtless of Quaternary age.

Geologic History.

The record of the earliest geological periods in the Basin region is even less well known than that of the Rocky Mountains. It is evident that the most ancient rocks were subjected to intense deformation which produced widespread metamorphism, and that they were intruded by granitic magmas. It is customary to refer these oldest rocks to the Archean. If C. D. Walcott is followed in assigning the pre-Olenellus sediments to the late Algonkian, then we have record of widespread sedimentation at that time. On the east, in central Utah, the Algonkian quartzite-slate series of the Wasatch Mountains continues into the Basin Ranges. A large part of this formation was probably laid down on a low land surface in a semi-arid climate. In western Nevada, large bodies of limestone referred to this time doubtless indicate marine conditions there. The position of the late Algonkian shore is all but unknown.

From the lower Cambrian and perhaps late Algonkian on until the Pennsylvanian period, the Basin Ranges element lay quietly beneath the ocean, except for brief interruptions during which the sea bottom emerged and was temporarily eroded, without deformation of the beds. These interruptions are not yet well correlated nor agreed upon by different students of the region. The best establisht are perhaps those which occurred in late Ordovician and mid-Pennsylvanian times. Great thicknesses of the Paleozoic rocks (even the limestones) are devoid of fossils, as if conditions were unfavorable to the growth of the higher marine organisms. At a few horizons, however, fossils are abundant. They show decided relationships with other circum-Pacific faunas and are generally distinct from those of the Atlantic region. The remarkable persistence of some species thru great thicknesses of strata has been pointed out by many students of the region. Thus, well known Devonian forms range far into the Carboniferous, suggesting a remarkable uniformity of conditions over long periods of time.

There is no record of the presence of the ocean over most of the Great Basin element after the Pennsylvanian period. On this account it is generally supposed that the region emerged in the Permian, and thereafter was only locally covered by the sea.

During the Triassic and Jurassic periods the restricted Pacific invaded the western edge of the Basin region and in the former period crost its northern end as far as Wyoming. Frequent alternations of shallow water sediments indicate that this was but a thin sheet of water, and gypsum beds may be taken to indicate that temporary oscillations left parts of the region exposed in a dry climate. In the Trias, at least, there were some volcanic extrusions along the Pacific shore. Louderback[1] finds

[1] Louderback, G. D., Basin Range Structure of the Humboldt Region. Bull. Geol. Soc. of Am., vol. XV, 1904, pp. 289–346.

evidence of a brief period of emergence at the close of the Trias, not attended, however, by noteworthy deformation. Late in the Jurassic period, while the Pacific thus bathed the western border of the Basin region, the long gulf from the Arctic Ocean must have temporarily bounded it on the northeast.

One of the most important events, on which nearly all observers are agreed, is the folding of the Jurassic and older rocks just before the Comanchean period. This Pacific revolution, best known in the Sierra Nevada, extended its effects eastward well into Nevada, where rocks as late as Jurassic are highly folded and intruded by bathaliths of granodiorite and gabbro. Inasmuch as the principal deformation in southern Arizona is known to have preceded the Comanchean it is not improbable that this disturbance extended eastward almost to New Mexico. On the eastern border of the Basin province in Utah there is no evidence of the Jurassic disturbance, and in eastern Nevada its effects have not yet been differentiated from those of the Laramide revolution (Cretaceous).

Since no Comanchean or Cretaceous rocks have been found in the Basin region except in southeastern Arizona, it is generally believed that the region was subject to erosion during those periods—altho the negativ evidence is inconclusiv. The Comanchean sea from the Gulf of Mexico spread westward far enough to reach the southeast corner of the region, but there is no evidence that the Cretaceous submergence of the Rocky Mountains extended so far west. From such meager evidence as is available, it seems that the late Mesozoic was a time of quiet planation without much deposition in inland basins and without notable volcanic activity. In northwestern Arizona the denudation was sufficient to remove all of the Paleozoic rocks down to the Archean complex.

At the close of the Cretaceous period the folding of the Rocky Mountain system affected also the eastern side of the Basin province. There can be little doubt that most of the folds of Utah were made at this time. Farther south the deformation was less pronounced, altho there seems to have been some faulting. There appears to be no direct evidence that the Rocky Mountain orogenic revolution was effectiv on the western border, adjoining California.

Enough has been learned about the Cenozoic history of the Basin Ranges element to show that it is complex and that it is not everywhere the same. Fossils are generally lacking and many of the facts are not as yet understood. The story involves a series of epochs of continental sedimentation chiefly in mountain valleys, as well as folding, faulting, and warping, with many recurrent volcanic eruptions. Probably thru most of the Tertiary period, as now, it was a region of mountains and basins, the former undergoing rapid erosion, while in the latter, sediments were being deposited on river-made plains, in lakes and playas. That the volcanic activity continued down almost to the present time is indicated by fresh cinder cones which are scattered here and there.

Deformation seems to have recurred at frequent intervals. There is clear evidence of moderate folding about the close of the Miocene period along the western side of the Basin region and doubtless more or less disturbance thru the province. A little folding seems to have taken place even as late as the Pleistocene, and Gilbert's[1] study of the old shore-lines of Lake Bonneville has shown that the region has been notably warpt even since the Pleistocene. Faulting, generally supposed to be of the tensional or normal type, but certainly including others, has broken the older structures. Some of the faulting occurred so long ago that all topographic features produced by it have been razed by erosion. On the other hand there is clear evidence in the fresh linear escarpments that much faulting has taken place in geologically recent times. It is the relativ importance, but not the existence, of these two generations of faults that is disputed.

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[1] Gilbert, G. K., Lake Bonneville, U. S. Geol. Survey, Mon. 1, 1890.

Important changes of climate in the Basin Ranges province since the end of the Cretaceous period are indicated by significant facts. The mountain glaciers and enlarged lakes of the Pleistocene period indicate much greater humidity than the present. On the other hand deposits of gypsum, salt and borates in the Tertiary strata as well as on the modern lake bottoms show that aridity prevailed at several earlier epochs. Coal seams in deposits thought to be of Eocene age are associated also with plant leaves and fresh water shells, all of which may be taken to indicate an earlier epoch of comparativly moist climate.

Physiography.

Topographic Features. The Basin Ranges element may be regarded as a plateau with an average elevation of 1200 to 1500 meters. In northern Nevada it rises to 2000 meters and in southeastern California there are depressions, such as Death Valley, as much as 100 meters below the sea. In detail the surface of the plateau is mountainous. It is covered from end to end with sub-parallel ranges which have a north-south trend in most parts of Nevada but a northwesterly trend in the southern part of the province. These ranges rise above the flat-bottomed valleys and basins like long islands from a sea of sand.

Most of the ranges have been eroded into bare irregular peaks and even isolated mountain groups. In some parts of the district, however, especially in the northwest, there are long escarpments with gentle back slopes which, according to Russell and Davis, are fault blocks scarcely modified by erosion. In addition there are a few little volcanic cones, the topography of which is purely constructional.

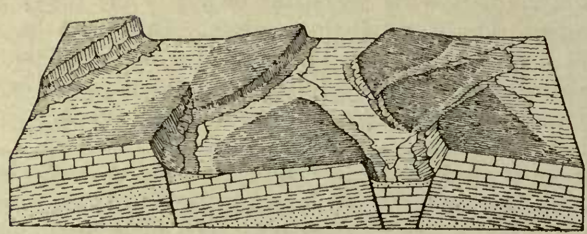

Fig. 44. Stereogram of young fault block mountains in southern Oregon (modified after W. M. Davis). The strata in the profile are purely conventional.

Many of the valleys are wide as compared with the mountains. Graded alluvial slopes extend out from the mountain bases toward the center of the valley which may itself be flat. On account of the dry climate very few of the valleys have permanent streams. Many of them have no outlets and contain either playas or saline lakes. Here and there groups of sand dunes have been formed, but for a desert region the Basin country is singularly deficient in such features. Over most of the valley floors the only visible material is gravel, sand, and finer detritus. The depth of this filling cannot generally be ascertained but in many cases it is thought to be hundreds of meters in thickness. On the other hand, it has been shown that similar plains in parts of New Mexico are really rock plains with but a thin veneer of waste.

Origin of the Topography. Much interest has been aroused by the topographic features of the Basin Ranges, but at present there are conflicting views as to the origin of them. In the seventies Gilbert concluded that the majority of the ranges were dislocated crustal blocks, the uplifted edges of which formed the mountains, while the depressed sides lay beneath the basins. He recognized that these blocks had been more or less modified by subsequent erosion. I. C. Russell later called attention to the mountains of extreme northern Nevada as examples of such fault blocks,—so young

that the original scarps have been merely gasht with short ravines while the back slopes remain almost unaltered. After a study of a large part of the Great Basin region, Spurr[1] vigorously dissented from this view, and advocated the hypothesis that the Basin Ranges in general are the product of prolonged erosion of a series of rocks folded and faulted at several different epochs. Approaching the problem from the physiographic standpoint, Davis[2] concluded that some of the Basin Ranges, at least, are elevated fault blocks as Gilbert and Russell first supposed. On the other hand he showed that others have been so deeply eroded that all the topographic effects of faulting, if ever present, have now disappeared.

In recent years the importance of the work of the wind in fashioning the topography has been pointed out by W. Cross, C. R. Keyes, W. M. Davis and others. Its efficacy in the sculpturing of rock outcrops is generally admitted, and there is growing adherence to the view that much of the topography of the southwestern desert region is due primarily to the wind, altho modified to some extent by the work of torrential rains.

Physiographic History. The history of the development of the existing surface features of the Basin Ranges province is evidently complex and is still very imperfectly known. Probably nearly all the existing topography of the region is of post-Cretaceous age as it is in other parts of the West. Considering the widespread and notable deformation of the Eocene and even Miocene deposits at least in Nevada, and the vast accumulations of mid-Tertiary volcanic materials, it is probable that most of the existing topography is no older than Pliocene. In the less disturbed parts of the Basin Ranges province, such as in Utah and Arizona, it may be possible to recognize a general peneplain surface,—the Mohave peneplain already mentioned in describing the Colorado plateaus (page 149). In the western part of the region, however, no such old surface seems to have been detected. Abundant evidence seems to prove that that region has been subject to more or less warping, faulting, and even folding in late Tertiary and even Quaternary times. If that is true, it was doubtless impossible for the processes of denudation to produce and preserve a baselevelled surface.

In a minor way climatic changes have had their effects. The Pleistocene lakes, of which Lahontan in Nevada and Bonneville in Utah were the largest, were brought into existence by an increase in the general humidity. Around the shores the waves carved cliffs and terraces and left many constructional forms such as bars, spits, and deltas. At its maximum extent Lake Bonneville overflowed northward into the Snake River, thus temporarily making an exception to the general fact of interior drainage in the Basin Ranges province. In its declining stages Lake Lahontan left thick deposits of calcareous tufa, encrusting the rocks and terraces in fantastic forms. From the masterly descriptions by Gilbert[3] and Russell[4] the history of these lakes is better known than those of most others in the world.

Seismicity.

The Basin Ranges are subject to more frequent shocks than the Rocky Mountain region (see map page 201). Altho very mild earthquakes have been felt nearly all over the Basin province, they have been much more abundant and severe along the western border. Observations near Virginia City and Lake Mono in western Nevada record

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[1] Spurr, J. E., Origin and Structure of the Basin Ranges. Geol. Soc. Am., Bull., vol. XII, pp. 217—270, 1901.

[2] Davis, W. M., The Mountain Ranges of the Great Basin. Harv. Mus. Comp. Zool., Bull., vol. 42, 129—177, 1903.

[3] Gilbert, G. K., Lake Bonneville, U. S. Geol. Survey, Mon. 1, 1890.

[4] Russell, I. C., Geologic History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, U. S. Geol. Survey, Mon. 11, 1885.

many earthquakes, some of which have been severe enough to cause damage to buildings.

The most important recorded earthquake since the region was settled about 1850, was the Owens valley earthquake of March 26, 1872. At that time a succession of violent shocks was felt and, had there been cities in the vicinity, it is certain that great damage would have been done. The Owens Valley earthquake was one of the first to be definitly connected with earth fractures. At the time of the quake a series of fissures more than 30 kilometers long, with changes of elevation amounting to 14 meters, made its appearance along the east base of the Sierra Nevada. It is generally believed that this was merely one of many little movements along the great Sierra Nevada fault zone, to which those mountains appear to owe their present height.

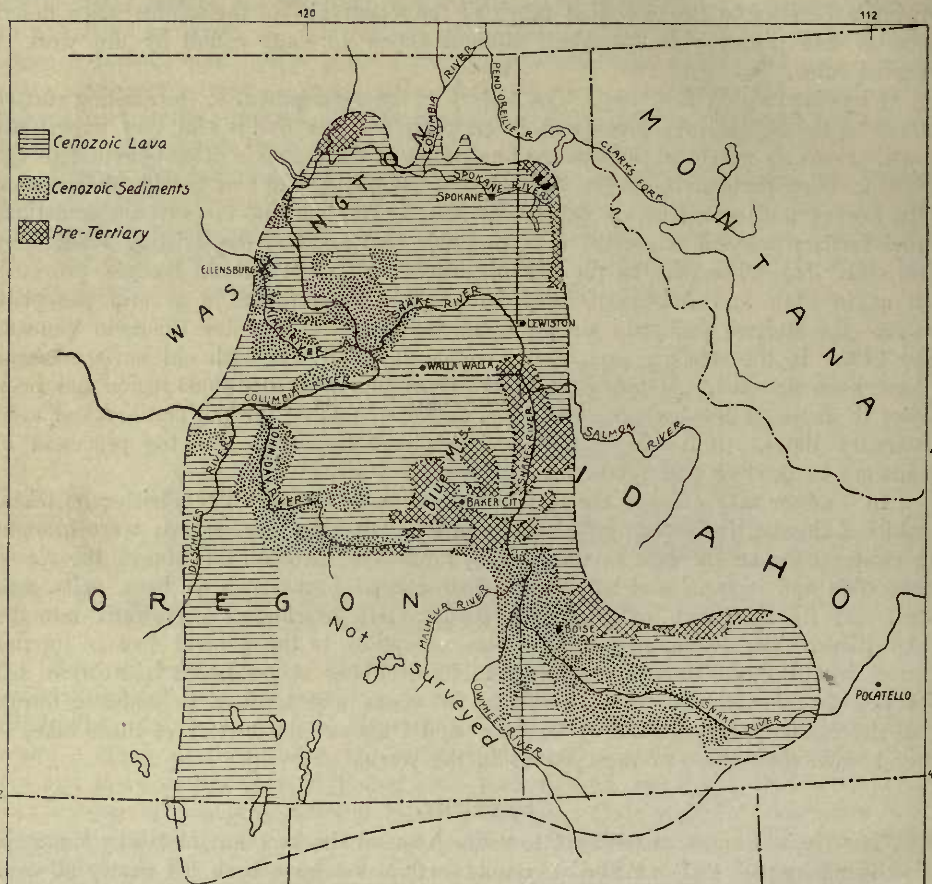
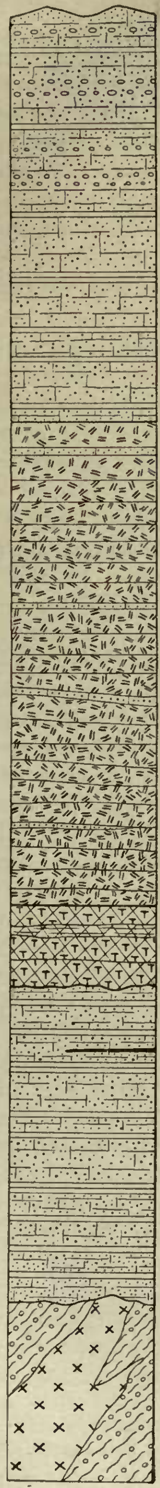


Fig. 45. Geologic sketch map of the Columbia lava plateau.

Columbia Lava Plateau.

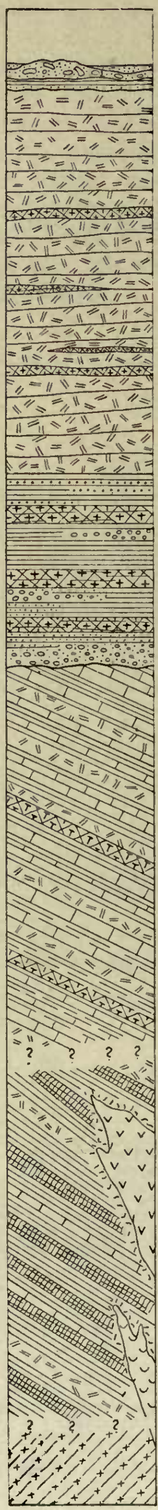
General.

The Columbia lava plateau occupies the northern part of the region between the great mountain systems in western United States. It varies in elevation from 500 to 2000 meters but is in general somewhat lower than the Basin Ranges province. It is drained by the Columbia River and its largest tributary, the Snake River. Over

Per.	Div.	Formation.	Strata.	M.	Description.
Miocene.	Upper (?).	Ellensburg.		300—450	Light colored friable sandstone, shale and conglomerate, with many pumis fragments and pebbles. *(Hipparion, Platanus dissecta).*
		Yakima.		300—600	Black basaltic lava, weathering gray or brown, compact or scoriaceous. Thin local beds of tuff.
		Taneum.		60—90	Loose-textured andesitic lava, with tuff and breccia.
		Unconformity.			
Eocene.		Manastash.		300+	Massiv, light-colored sandstone and conglomerate, with shale and seams of impure coal. (Plant fossils).
		Angular unconf.			
Pre-Tertiary. (? Paleozoic.)		Easton.			Silvery quartz-mica schist, amphibolite and epidote schist, intruded by granitic batholiths.

GENERALIZED SECTION IN CENTRAL WASHINGTON.[1]

[1] Near Ellensburg, Washington, after G. O. Smith, U. S. Geol. Survey, 1903.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.	Upper.	Alluvium.		?	Gravel, sand and clay, deposited in streams and lakes.
		Glacial.		?	Terraced glacial outwash deposits along streams.
		— Unconformity. —			
Pliocene.		Idaho.		?	Fluviatile and lacustrine sediments containing *Mastodon americanus*, and *Elephas columbi*.
Miocene (?).				?	Chiefly flows of basalt, with rhyolitic and andesitic flows and tuffs.
Eocene.	Upper?	Payette.		?	Lacustrine silt and gravel with rhyolite tuffs.
		— Unconformity. —			
Triassic.				Several thousand feet.	Limestone and calcareous shale interbedded with basaltic and andesitic flows and tuffs, now much altered. *(Halobia, Pentacrinus,* and *Turritella?)*
Carboniferous, etc.				Several thousand feet.	Chert, argillite, slate and basic lavas, with small bodies of limestone, intruded by diorite and serpentine (Carboniferous fossils found in one locality).
Archean (?).				?	Coarse-grained biotite gneiss.

FORMATIONS OF THE BLUE MOUNTAINS, OREGON.[1]

[1] Modified after W. Lindgren, U. S. Geol. Survey, 1901.

large areas the Columbia Plateau is relativly flat, but in the south and everywhere about its borders it is interrupted by mountains of increasing height, and locally in the south its surface is intersperst with volcanic hills. The climate is dry, especially toward the south. The mountains are forested, but the plateau is clad with sage brush. More favored portions are suitable for wheat culture without irrigation, but in the southwest the land is essentially a desert. In a large way the origin of the Columbia plateau is simple. It was formerly a hilly or mountainous land, but is now levelled up by many successiv horizontal flows of igneous rock, chief among which is basalt. The flows are partly Eocene but principally Miocene. Since the volcanic outpourings, the larger rivers have cut deep canyons into or even thru the volcanic strata.

Stratigraphy.

In the Columbia Plateau there are two distinct groups of rocks. The older consists of semi-metamorphic sediments with igneous intrusions. These are imperfectly known, but are probably of pre-Comanchean age. The younger group, belonging to the Tertiary and Quaternary systems, comprises vast quantities of volcanic flows with subordinate tuffs, and continental deposits which are locally thick.

Pre-Tertiary Rocks. The older rocks are probably northward continuations of better known terranes of the provinces farther south. Along the northeastern side of the Columbia plateau a series of quartzites and slates, traverst by granitic and other intrusions, prevails. The sediments are more or less schistose and are now correlated with the late Proterozoic (Belt series) of Montana. Probably the succession includes some later Paleozoic beds, since they are the prevalent formations along the southeast border. Beyond the fact that the granites have been intruded into the sediments and are pre-Tertiary, their age is unknown. Since they are not far from the Rocky Mountain system it may be suspected that they are post-Cretaceous, but they bear some resemblance to the late Jurassic intrusions of the Pacific ranges.

On the west the rocks also include metamorphic sediments and intrusiv igneous rocks. The best known occurrences within the Columbia Plateau have been found in the island-like Blue Mountains of northeastern Oregon and the adjacent canyon of Snake River. Bodies of gneiss there are regarded by Lindgren[1] as Archean. Thick beds of slate and chert with a few problematical fossils are believed to be Carboniferous. Massiv Triassic limestone and shale with interbedded sheets of lava and breccia have been identified by fossils, and the existence of the Jurassic is suspected. In the John Day basin, northwest of the Blue Mountains, J. C. Merriam has found a thick series of Comanchean and Cretaceous rocks faunally related to the Knoxville and Chico formations of California. Batholiths of granodiorite and gabbro have been intruded into most of the older terranes, altho it does not appear that they cut the post-Jurassic beds. In brief it may be said that the rocks along the western side of the Columbia Plateau are essentially a part of the Pacific Mountain system and agree with it in stratigraphy and structure.

Cenozoic rocks. Considering the plateau as a whole, the most abundant Tertiary rocks are lava flows. There are, however, intercalated beds of continental sediments which are very thick locally on the west, and in addition there are considerable accumulations of volcanic tuff. To these may be added the usual superficial deposits of glacial drift, alluvium, and soils.

Generally where the plateau has been carefully studied the Tertiary rocks have been divided into an older and a younger series. For example, in the Yakima region of central Washington, a thick sandy series of middle Eocene age with a succession

[1] Lindgren, W., The Gold Belt of the Blue Mountains of Oregon, U. S. Geol. Survey 22nd Ann. Rept., Pt. 2, 1901.

of basalt flows are separated from the younger basalts by a definit unconformity,—the older formations being somewhat folded. The younger lava flows are succeeded by a fluvio-lacustrine formation with beds of volcanic ash and Miocene plants.

From other parts of the Columbia Plateau roughly similar sections are reported. The older series generally contains more rhyolitic and andesitic flows with thick beds of tuff. The vertebrate and plant fossils which have been found at many points agree in indicating middle to late Eocene age.

The most conspicuous single formation of the region is easily the Miocene basalt, which covers the entire district. Its average thickness can hardly be less than 1000 meters and it is known to be more than 1600 meters deep in some places. In the many superb canyon sections the succession of individual flows, each 20 to 30 meters thick, can be counted one upon the other. At the contacts between the flows, slaggy surfaces may generally be seen, and the beds are in some cases separated by thin sheets of ash or normal sediments. Olivine basalt is the prevailing type. The flows are generally believed to have issued from long fissures without the usual accompaniments of eruptions. In southern Idaho, however, I. C. Russell advocates the view that the flows issued from craters and that the flatness of the topography is due merely to the very liquid character of the lava. Altho the great lava floods were evidently poured out in Miocene times there is abundant evidence that eruptions continued or recurred in Quaternary and perhaps even in recent times. The fresh slaggy lava flows and cinder cones which are well sprinkled over the surface of eastern Oregon and southern Idaho have all the marks of extreme youth. They have been vividly described by Russell in several papers.[1] In the northern part of the region such evidences of late volcanic action are lacking.

Along the northern edge of the province a thick sheet of glacial drift is spread out over the edge of the plateau in several places; it shows the characteristic moraine topography and scattered bowlders, many of which are remarkable for their enormous size. Widely distributed over central Washington and doubtless other parts of the plateau is a deposit of loess 5 to 10 meters thick, which, according to Calkins[2] is of eolian origin, in part at least derived from glacial flood deposits. Aside from these formations the Quaternary beds consist chiefly of gravel and sand as in the Basin Ranges element farther south.

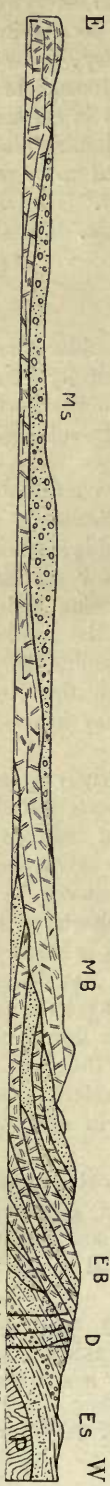


Fig. 46. Profile of the edge of the Columbia lava plateau near Mount Stewart, Wash. (After G. O. Smith, U. S. Geol. Surv.) — P, Paleozoic schists; Es, Eocene sandstone and shale; D, dikes of basalt; Eb, Eocene basaltic flows and sediments; Mb, Miocene basaltic flows; Ms, Miocene continental sediments.

Structure.

Pre-Tertiary Rocks. The older rocks beneath the plateau-making beds are everywhere folded and in many places much metamor-

[1] Russell, I. C., A Geological Reconnaissance in Central Washington, U. S. Geol. Survey, Bull. 108, 1893. A Geological Reconnaissance in Southeastern Washington, U. S. Geol. Survey, Water Supply Paper, No. 4, 1897. A Geological Reconnaissance in Southern Oregon, U. S. Geol. Survey, Annual Report 4, 1884, pp. 431—464. The Geology and Water Resources of the Snake River Plains of Idaho, U. S. Geol. Survey Bull. 199, 1902. Notes on the Geology of Southwestern Idaho and Southeastern Oregon, U. S. Geol. Survey, Bull. 217, 1903.

[2] Calkins, F. C., Geology and Water Resources of a portion of East-central Washington, U. S. Geol. Survey, Water Supply Paper 118, 1905.

phosed. Furthermore the folded beds are intruded by large batholiths of igneous rocks. The folds have the same trends as their continuations in the Basin region on the south. There is much evidence that the Columbia Plateau is structurally a part of the Basin Ranges province modified by volcanism in Tertiary times.

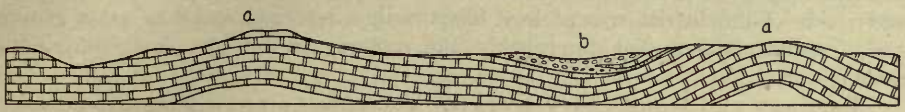


Fig. 47. Profile near Ellensburg, Wash., on the west edge of the Columbia plateau, showing folded Miocene lava flows (a), overlain by Miocene sand and gravel (b). (After G. O. Smith, U. S. Geol. Surv.)

Tertiary and Quaternary Beds. The post-Cretaceous rocks are either horizontal or mildly deformed by folding or normal faulting. More specifically, the Eocene formations along the western side of the plateau have been comprest into low rolling folds with irregular but generally northerly trends. The great Miocene flows and sediments which rest unconformably upon the Eocene have been much less disturbed, and yet even in them low anticlinal and synclinal flexures can be detected. Some of these are unsymmetrical, being steeper generally on the north or east. Smith and Willis[1] conclude that these younger flexures are due to recurrent movements along lines establisht at a much earlier time. In the southwest part of the plateau, especially in southeastern Oregon, the Miocene beds appear to be not only slightly folded but also faulted.[2] In brief there is a transition between the faulted structure of the Basin Ranges province on the south and the unbroken Columbia Plateau on the north. Altho there is evidence of important changes of level during Quaternary times the glacial and alluvial deposits remain essentially undeformed.

Geologic history.

For many reasons the geologic history of the Columbia Plateau is still imperfectly known. The prevalence of igneous rocks, the scarcity of fossils in many of the continental sedimentary beds, and the burial and partial metamorphism of the older rocks, combine to render correlation difficult.

Pre-Tertiary Events. On the east there is record of prolonged sedimentation corresponding probably to that which characterized the late Proterozoic era in the Rocky Mountains. Almost without doubt the region was beneath the sea thru a large part if not all of the Paleozoic era, but of this there is only a meager record within the district. At some time before the Tertiary period the older rocks were subjected to deformation which left them highly folded, faulted and invaded by large intrusions. Judging from the proximity of this side of the plateau to the Rocky Mountain system, it may be suspected that this disturbance came at the close of the Cretaceous; but there, as in Nevada and Idaho, no line has yet been drawn between the area affected most at the close of the Cretaceous and that affected chiefly at the close of the Jurassic.

Along the western side of the plateau there is a dim altho assured record of marine sedimentation in at least the Carboniferous and Triassic periods and possibly

[1] Smith, G. O., Contributions to the Geology of Washington; Geology and Physiography of Central Washington; and Willis, Bailey, Physiography and Deformation of the Wenatchee-Chelan district, Cascade Range. U. S. Geol. Survey, Prof. Paper 19, 1903.

[2] Waring, G. A., Geology and Water Resources of the Harney Basin region, Oregon, U. S. Geol. Survey, Water Supply Paper 231, 1909.

Russell, I. C., Geological Reconnaissance in Southern Oregon. U. S. Geol. Survey, Ann. Rep. 4, 1884.

in the Jurassic also. This was terminated by the great Pacific revolution about the end of the Jurassic period, resulting in the folding of the rocks and the intrusion of granodioritic and other magmas.

The condition of the Columbia Plateau region in the Comanchean and Cretaceous periods is largely doubtful. The sediments of the John Day valley indicate that the western side of the district was at least temporarily submerged and was rather generally a site of sedimentation. Not improbably the eastern portion was land during these periods.

Tertiary and Quaternary Events. The surface preserved beneath the Eocene deposits shows that the Columbia region was hilly or mountainous early in the Tertiary period. Much of this topography was later buried beneath gravel and sand laid down presumably by aggrading streams, but, no doubt, partly in lakes. Widespread volcanic eruptions during the later part of the Eocene period left thick accumulations of volcanic ash and vast flows of basic and acidic lava.

The Eocene formations were then gently folded and eroded to a mature surface of mountainous relief. There seems to be no local evidence for fixing the age of this deformation more exactly, but it may be suggested that this corresponds to the widespread middle Miocene disturbance of the whole Pacific region. In and probably late in the Miocene period volcanic eruptions were resumed on a grand scale. Each flow spread over a wide area and left a comparativly thin bed of jointed lava. It is evident that the flows did not necessarily follow each other in rapid succession for time must be allowed for the accumulation of the intercalated sediments. One need not, therefore, like a certain imaginativ writer, picture the Columbia region as a veritable molten sea in Miocene time.

Immediately after the outpourings of basalt had ceast, or nearly ceast, much of the plateau region became the site of sedimentation partly in lakes and doubtless partly on river plains. Further eruptions along the edges of the district contributed much volcanic ash to the formation of these sediments. At a somewhat later time, with reference to which students of the region are not all agreed, the Miocene and older deposits were mildly deformed, thus leaving the lava beds in broad gentle arches and depressions thruout most of the plateau region, and in the south at least producing notable faults. According to the physiographic studies of Smith and Willis[1] the deformation about the close of the Miocene was the most important, altho there are signs of its continuation at a later time. On the other hand the freshness of the fault scarps in southern Oregon have led to the belief that the deformation there was post-Pliocene.

During the glacial period great lobes of ice from the snow fields of British Columbia descended the north-south valleys and spread out over the northern border of the lava plateau. It is thought also that this event had a direct relation to the formation of the rich soil of central Washington. On a few of the isolated mountain groups such as the Stein and Blue mountains in Oregon, the summits of which reach an elevation of 3000 meters, small mountain glaciers came into existence. Their effects, however, were trivial.

Physiography.

Topography. A plateau,—as indicated by its name,—this province varies in elevation from 500 meters in central Washington to 1000—1200 meters in Idaho and to more than 1700 meters in southeastern Oregon. In its northern and eastern parts its surface is relativly flat in the gross, except for the canyons by which it is intrencht. Around its borders spurs and ridges jut out into it from the surrounding mountains, and here and there island-like peaks and groups of mountains rise out of

[1] Op. cit.

it as from a sea. The Blue Mountains of Oregon are perhaps the largest of these groups. In the southwestern part, the plateau is more diversified with bold escarpments and ridges.

In detail the surface is much rougher than the preceding description might imply. In Oregon and Idaho, particularly, there are many isolated hills, locally known as „buttes"; some of these are lava domes, while many are recent volcanic cones. There are also pit-craters, and the surface here and there is so strewn with recent volcanic products that it is very rough. The features of this district have been admirably described by RUSSELL.[1]

Into the surface of the plateau deep canyons have been cut. The largest are those of the Columbia and its chief tributary the Snake River; the valley of the latter is in places more than 1500 meters deep. Along the terraced walls of these gorges the successiv flows of columnar basalt stand out with the clearness which is characteristic of an arid land. In all but the marvelous colors these canyons almost rival that of the Colorado River in Arizona. In addition to the valleys of the large rivers and their proper tributaries, there are other canyons in Washington which are no longer occupied by streams. The best known and largest of these is the Grand Coulee.

Origin and History of the Land Surface. In outline, the history of the topographic development is comparativly simple, but most of the details still await interpretation.

In late Miocene time the great floods of basalt levelled up an old mountainous basin between the Pacific and Rocky Mountains and ran finger-like extensions into all the broad surrounding valleys, leaving only a few isolated mountain tops protruding above the general surface. By this means the plateau came into existence. Immediately after the eruptions ceast, sediments were strewn widely over the surface and further assisted in making the topography plane. The subsequent history involves the erosion of the canyons and the modification of the surface in detail. This chapter of the physiographic history is by no means simple and a confident interpretation cannot be given here.

The Columbia valley, on the northwest side of the plateau, has been subjected to a careful physiographic study by WILLIS and SMITH.[2] According to their interpretation, the surface of the plateau, after having been slightly folded, was reduced to a peneplain, which likewise extended westward over the Cascade Mountains. They assign this work to the Pliocene period. In consequence of a moderate uplift the drainage was rejuvenated in late Pliocene or early Quaternary times and wide shallow valleys were excavated in the surface of the plateau. This was followed later by much greater uplift with slight differential warping of the surface. As a result the streams have trencht the plateau in deep canyons which are antecedent to the low transverse arches produced by warping.

Glaciation in the late Pleistocene served to alter the forms of some of the canyons on the west edge of the plateau and caused various changes of drainage. One of the most remarkable of these, pointed out earlier by RUSSELL, consisted in the diversion of the Columbia River by the great Okanagan glacial lobe. Being crowded southward by the ice, the river cut new channels through the plateau; but after glaciation it returned to its former canyon and left the temporary valleys or "coulees" without streams. Doubtless related to glaciation are the thick deposits of sand and gravel with which many of the canyons were clogged. In recent times, the rivers have re-excavated much of these deposits, leaving a series of conspicuous gravel terraces along the Columbia and some of its tributary rivers.

[1] RUSSELL, I. C, Geology and Water Resources of the Snake River Plains of Idaho. U. S. Geol. Survey, Bull. 199, 1902.

[2] Op. cit.

Not all of these stages have been recognized generally over the plateau region, doubtless because other areas have received less attention from physiographers. In southeastern Oregon, WARING[1] regards the topography as largely constructional, due in the first instance to vulcanism and in the second to the dislocation of the blocks of the plateau along faults, giving rise to scarps and dip slopes with intervening structural depressions. To the work of streams is assigned merely the detailed modification of these features, and the cutting of a few important canyons.

Seismicity.

The available data indicate that, except perhaps in the southwest part of the plateau, earthquakes are neither frequent nor violent in the Columbia Plateau. No destructiv earthquakes have taken place in the district during the historic period; but that stretches back little more than a century. Considering the fact that the central and northern parts of the plateau bear little evidence of geologically recent faulting, it is perhaps not surprising that it should be seismically more quiet than the Basin Ranges farther south.

Sierra Nevada and Cascade Mountains Element.

General.

The great mountain range which separates the interior plateau region from the lowlands and coast ranges of the Pacific slope is called the Sierra Nevada in California and the Cascade Range farther north. It is convenient here to treat both as parts of a single geologic element.

The Cascade Range enters the United States at the 49th parallel and trends southward into Oregon, gradually losing its identity as a well defined range. From southern Oregon the range bends more toward the southeast, forming the back-bone of the state of California under the name of the Sierra Nevada. Thru most of this distance of more than 1700 kilometers the chain is well separated from the Coast Ranges by a series of depressions, the largest of which is the valley of California. In northern California and southern Oregon, however, the Sierra Nevada-Cascade system is merged with the more westerly ranges. The name Klamath mountains is somewhat loosely applied to the ill-defined mountain mass which marks this junction. Again, in southern California, the Sierra Nevada joins the Coast Ranges in a horse-shoe curve which encloses the southern end of the great valley.

In general the range is a broad massif rather than a well defined ridge. The surface of this has been carved into many irregular peaks, the highest of which are clad with snow and glaciers. On the east the descent to the Basin plateau is generally steep but on the west far more gentle. The Sierra Nevada is regarded as a fault block tilted westward, while the Cascade range proper, which shows little difference of slope, is believed to be a dissected upwarp. From the surface of this massiv range, particularly along the western slope, rise volcanic cones,—Mt. Shasta and Mt. Ranier being the highest and most renowned. One may consider them as adventitious features of the Cascade system.

Thruout the range the succession of formations is roughly the same, but on the other hand there are many local differences. The rocks may readily be divided into two grand divisions. The older consists of highly folded sedimentary and volcanic rocks which have been largely metamorphosed and are invaded by intrusions of many kinds of igneous rocks. This older series is known to comprise terranes ranging in age from Silurian to late Jurassic, and there may well be older rocks among its

[1] Op. cit.

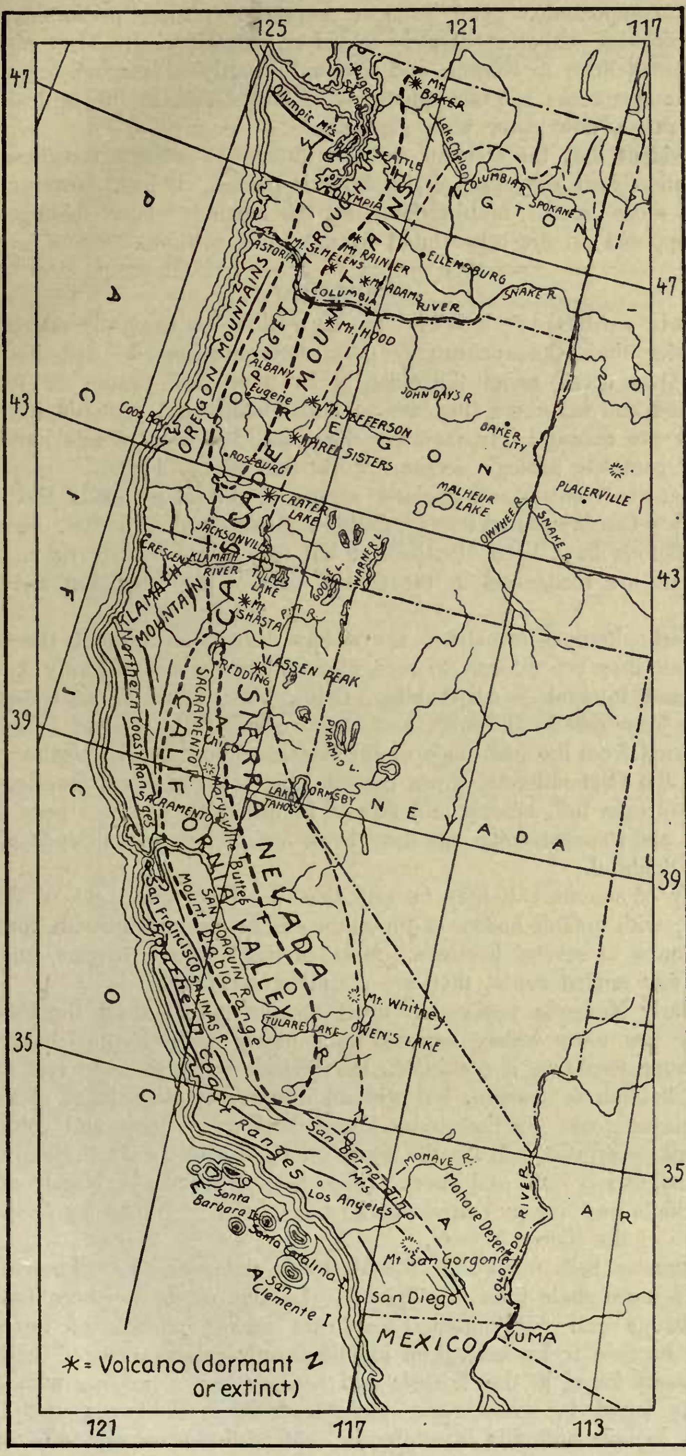


Fig. 48. Sketch map of the Pacific Coast elements.

unrecognized components. The younger sequence consists predominantly of sandy sediments which are either moderately folded or still flat-lying. They represent various ages from Comanchean to Recent, and are only partly of marine origin. Associated with these younger rocks are vast quantities of lava which, in the central and northern parts of the range, now cover wide expanses.

It is evident that the element owes its dominant geologic structure to the great Pacific revolution near the close of the Jurassic period. It has, however, been greatly modified by more recent faulting and in the north by later folding and volcanic activity, all opposed on the other hand by unceasing erosion.

Stratigraphy.

Jurassic and Older Rocks. In this region the generally altered condition of all rocks older than Comanchean renders determinations of age in many places impossible. Over large areas the older rocks have been more or less completely metamorphosed and in others they are so much folded and replaced by igneous rocks that relations are doubtful. In favorable localities, however, fossils have been found and tolerably complete geologic sections workt out (see p. 174).

Altho ancient schists and gneisses appear at several points in the province, the existence of pre-Cambrian rocks has not been determined. In fact, formations older than Carboniferous have been identified at but few places in the region. Silurian and Devonian strata are recognized in the central part of the range but not farther north or south.

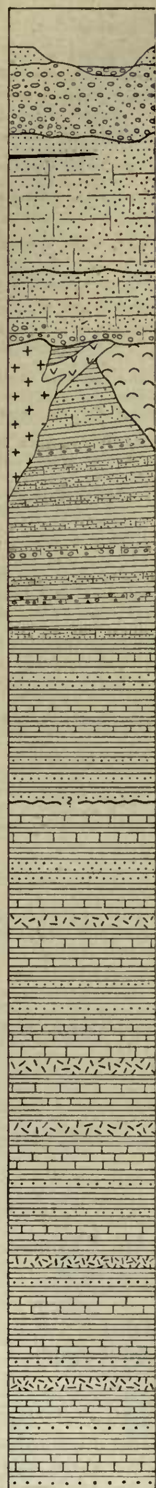
The Carboniferous formations are widely distributed thruout the Cascade-Sierra mountains; but they are difficult to recognize and hence are definitly known only at widely scattered intervals. At Redding, Calif., the system is separated by a slight unconformity from middle Devonian and older rocks. Beds thought to be of the same age are reported from the east slope of the Cascade Mountains in northern Washington. In California the Carboniferous strata consist largely of slate and limestone with much intercalated volcanic tuff, breccia and flows. In this thick series of beds fossils of both Mississippian and Pennsylvanian age have been found, but the existence of the Permian seems to be doubtful.

By way of summary it may be said that the Paleozoic rocks of this region are largely pelitic, with notable bodies of limestone and sandstone and with contemporaneous volcanic products at several horizons. Most of the beds are marine, and, altho interrupted by a few eroded zones, they are a unit structurally.

The early Mesozoic rocks are much better known than the Paleozoic, partly because they are more widely exposed and partly because they have yielded more fossils. In some localities, if not in all, the Triassic rocks seem to rest unconformably upon the Carboniferous beneath, but without noteworthy discordance of structure. The prevailing Triassic rocks are limestones interbedded with shales and volcanic products. Sandy and conglomeratic beds usually lie at the base, and locally there are considerable deposits of radiolarian slate and chert. These beds appear to be largely of late Triassic age, altho middle and lower Triassic rocks have been identified by J. P. Smith along the east slope of the Sierra Nevada.

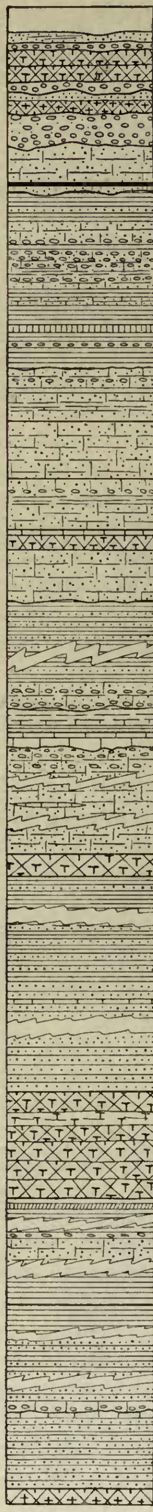
The Jurassic beds, of which the Mariposa slates are best known, contain less limestone and more shale than the Triassic. Locally, as in northern California, thick beds of sandstone and conglomerate form the middle portion of the system. The Triassic and Jurassic rocks have been identified only rarely north of California.

The fossils found in the Triassic and Jurassic are all marine with the exception of land plants found in some upper Jurassic beds in California and Oregon. The marine types include not only invertebrates, but ichthyosaurs and other reptils which have been made known by J. C. Merriam. They may be correlated with European

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.					Soil and gravel.
		Unconformity.		30+	Sand, gravel and conglomerate on terraces.
				120	River and shore gravels.
		Unconformity.			
Neocene.		Ione.		245	Clay, sand and sandstone, with thin coal seams. (Only along edge of mountains).
		Unconformity.			
Cretaceous.		Chico.		120	Tawny sandstone and conglomerate.
		Angular unconf.			
Juratrias.					Intrusiv granitic rocks, — granodiorite, diorite and gabbro.
		Mariposa.		?	Black slate with many beds of gray sandstone and conglomerate. *(Perisphinctes colfaxi* and *Olcostephanus lindgreni).*
		Sailor Canyon.		300	Gray and black calcareous slate, with interbedded quartzite and limestone. *(Daonella* and *Monotis).*
		Unconformity (?).			
Carboniferous and older.		Calaveras.		1200+	Argillite, limestone, quartzite, chert and slate, with interbedded greenstones. Locally metamorphosed to schists.

FORMATIONS IN THE GOLD BELT OF THE CENTRAL SIERRA NEVADA, CALIFORNIA.[1]

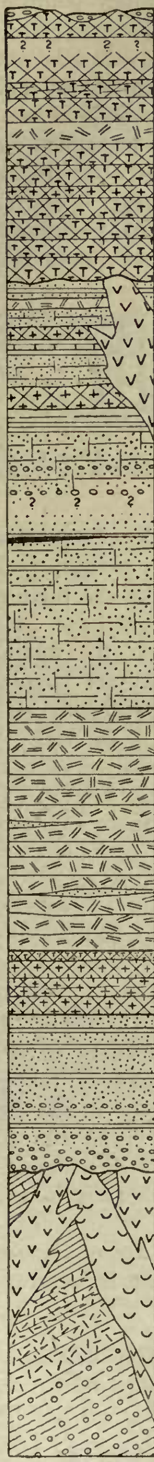
[1] After W. Lindgren and others, U. S. Geol. Survey, 1898.



Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.		Allnvium.		30±	Sand and clay in valley flats.
Tertiary.				15	Auriferous gravel of lava pebbles.
				90+	Andesitic flows, breccias, and tuffs.
				30	Auriferous gravel containing some lava pebbles.
				60	Rhyolitic tuff in sandstone and fine conglomerate.
				90	Auriferous gravel; pebbles composed of quartz and old volcanic rocks.
Cretaceous.				120	Chiefly arkose sand, with occasional carbonaceous beds at base.
Jurassic.		Angular unconf.			Intrusions of serpentine, granodiorite, quartz porphyry, diorite, and meta-andesite.
	Upper.	Foreman.		500—750	Chiefly gray shale, with some shaly sandstone and traces of fine conglomerate. Chiefly fine sandstone; in many places shaly. Beds of conglomerate and some shale. Chiefly shale, with thin beds of conglomerate of cherty quartz (*Pecten, Astarte, Trigonia naviformis?* and plants).
		Slight unconf.			
	Middle (?).	Hinchman.		150 - 300	Coarse tuffaceous sandstone with some shale and conglomerate of andesitic material. (*Camptonectes bellistriatus, Stylina lubulifera, Gryphaea curticei*, etc.).
		Bicknell.		150—400	Tuffaceous gray sandstone, with brownish-red sandstone below. (*Gryphaea bononiformis, Entolium coslatum, Trigonia obliqua*, etc.).
	Lower.	Mormon.		150	Massiv to shaly gray sandstone, local red and green conglomerate. (*Lima dilleri, L. taylorensis, Ctenostreon, Trigonia, Entolium*, etc.).
		Thompson.		3—9	Gray and red limestone lentils in red calcareous shale. (*Nerinea, Opis*, etc.)
		Fant.		45+	Altered andesitic flows and tuff conglomerate.
		Hardgrave.		140	Fine red to coarse gray tuffaceous sandstone. (*Pecten acutiplicatus, Entolium meeki* and *Pinna expansa*).
		Unconformity.			
		Trail.		885	Slaty gray to purplish shales, with some interbedded sandstone and conglomerate. The conglomerate is chiefly below and contains much volcanic matter. (Fresh-water bivalves and plants).
		Unconformity.			
Triassic.	Upper.	Swearinger.		60	Dark slaty calcareous shale, with thin limestones and some siliceous beds. (Fossils homotaxial with upper Noric stage of the Alps).
		Hosselkus.		43	Dark blue to light gray limestone. (*Arcestes, Spiriferina, Tropites, Juvavites*, etc.).
		Unconformity.			
Carboniferous.	Upper.	Robinson.		450	Conglomerate, largely tuffaceous with some sandstone and shale. Limestone lentils in sandstone and tuff. Reddish brown calcareous and tuffaceous sandstone. (*Productus semireticulalus P. punctatus?, Spirifer cameratus, Fusulina elongata*, etc.)
		Reeve.		60	Porphyritic meta-andesite and tuff.
	Lower? Calaveras group.	Peale.		425	Reddish-brown slaty shales; tuffaceous sandstone and fine conglomerate containing lapilli. (*Spirifer striatus, Phillipsia, Ambocoelia planiconvexa*, etc.)
		Shoo Fly.		2040+	Thin beds of gray quartzite and occasional lentils of limestone; locally black, gray and red cherts (*Fusulina*).
		Taylor.		300+	Green meta-andesite; lava flows, tuff and volcanic conglomerate.
		Arlington.		1750	Chert, dark gray slaty shale and conglomerate. Fine gray thin-bedded sandstones. Gray and yellowish shales.
Devonian (?).		Taylorsville.		550	Chiefly slaty shales. Chiefly light colored quartzite. Local conglomerate at base.
		Unconformity.			
Silurian.		Montgomery.		9	Bluish gray limestone. (*Syringopora, Halysites catenularia, Heliolites*).
Pre-Silurian (?).		Grizzly.		120—300	Gray thin-bedded quartzite, with some dark slaty shale.
		?		?	Gray metarhyolite, locally brecciated.

FORMATIONS OF THE NORTHERN PART OF THE SIERRA NEVADA.[1]

[1] Adapted after J. S. Diller, U. S. Geol. Survey, 1908.



Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.					Glacial drift and thin layers of volcanic ash.
Pliocene (?).		Howson.		75	Porphyritic hornblende-andesite lava.
		Sequence broken.			
Miocene.	Upper?	Keechelus.		1200	Lava, breccia, and tuff. Chiefly pyroxene-andesite, but including considerable dacite and some rhyolite and basalt.
		Snoqualmie.			Granodiorite batholiths and dikes.
		Angular unconf.			
	Lower?	Guye.		1100+	Shale, sandstone, grit, and conglomerate, with a little limestone and chert, and contemporaneous flows of basalt and rhyolite. *(Platanus dissecta, Acer aequidentatum).*
		Sequence broken.			
Eocene.		Roslyn.		1000+	Massive yellow sandstone, with clay and shale; coal beds in upper portion.
		Teanaway.		1200	Basaltic lava flows, with interbedded layers of tuff, and a little sandstone, basic andesite and rhyolite. (Plant fossils in sandstone).
		Kachess.		0—600	Mostly laminated rhyolitic lava and a little tuff. Thin andesite near the top.
		Swauk.		60—1500	Well-stratified conglomerate, arkose, quartzose sandstones, and shale, light and dark gray in color. (Fossil plants).
		Unconformity.			
Pre-Eocene.	Intrusives.	Mount Stuart.			Massiv gray granodiorite, locally porphyritic.
		Peridotite.			Massiv peridotite, somewhat porphyritic; partly altered to serpentine.
		Quartz-diorite.			Light gray granular hornblendic rocks, distinctly gneissic.
Paleozoic (?).		Peshastin.			Black slate, with bands of chert, thin beds of grit, and lenses of limestone.
		Hawkins.			Breccia, tuff, and amygdaloid, usually of diabasic composition, altho much altered.
		Easton.			Silvery green quartz-mica-schist; amphibolite and epidote-schist less prominent; some bluish carbonaceous schist.

GENERAL SECTION OF ROCKS IN CENTRAL CASCADE MOUNTAINS OF WASHINGTON.[1]

[1] After G. O. Smith and F. C. Calkins, U. S. Geol. Survey, 1906.

faunas ranging from the Lias to the Upper Oolite, and they indicate a close relationship between this province and the Eurasian region.

The early Mesozoic rocks, or as they are often called in the United States, the "Jura-Trias" beds, have been transformed into slates, quartzites and even schists. They are associated with and locally metamorphosed by intrusions of several kinds of igneous rocks, including granite, gabbro and serpentine. Most prominent among these intrusions are the batholiths of granodiorite which interrupt the older rocks thruout the Sierra Nevada-Cascade range. Most of these intrusions appear to have been formed at the end of the Jurassic period, and with them are genetically connected the gold-bearing quartz veins from which much of California's wealth has been taken.

Fig. 49. Profile in the Sierra Nevada Mountains near Lake Tahoe, Cal.: a, Jurassic or older slate and schist; b, granodiorite; c, andesite flows and breccia; d, altered diabase. (After W. Lindgren, U. S. Geol. Surv.)

The Jurassic and older rocks make nearly all of the Sierra Nevada. In the northern part of the Cascade mountains, however, younger rocks form an integral part of the range. On account of the fact that the rocks are there more metamorphosed than in the south, are much more heavily forested, and have been less studied, they are still but little known. Smith and Calkins[1] report the finding of Jurassic fossils near the 49th parallel, but the ages of the older rocks are largely conjectural.

Post-Jurassic Rocks. Younger rocks of several different ages are exposed in the Sierra Nevada-Cascade Range, but the sequence is far less complete than in the Coast Ranges farther west. In the Sierra Nevada these rocks have been found along the west base and, in the form of superficial deposits, scattered here and there over the surface. In the Cascade Range there is a much more complete representation, but it has received less study. In the form of lava flows and breccias, post-Jurassic rocks make up nearly all of the range from Washington south to northern California.

The Comanchean system altho well represented in western California has not been detected in the Sierra Nevada. In northern Washington, Smith and Calkins have found, near the northern end of the Cascade range, a thick series of black slate and sandstone in which a few late Mesozoic fossils were found. These are thought to be lower Cretaceous, — equivalent to the Shasta series of California. Daly[2] reports in the Okanagan region, on the 49th parallel, a great thickness of arkosic sandstone and conglomerate, probably of the same age. The Cretaceous (upper) system is a little better represented. Along the western slope of the range it has been found in northern California and southern Oregon, and beds believed to be equivalent are exposed in northern Washington. The formation there known as the Chico[3] generally consists of sandstone and shale with a basal conglomerate which rests in markt unconformity on many older rocks.

Nearly all the superficial rocks of the range are of Cenozoic age. Among the sediments Miocene is most widespread, but the Eocene is well represented, particularly in the northern part of the Cascade Mountains.

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[1] Smith, G. O., and Calkins, F. C., A Geological Reconnaissance across the Cascade Range, near the 49th parallel, U. S. Geol. Survey, Bull. 235, 1904.

[2] Daly, R. A., The Okanagan Composite Batholith of the Cascade Mountain System. Bull. Geol. Soc. of Am., vol XVII, 1906, pp. 329—377.

[3] For a more detailed description of the Chico see page 184.

From southern Washington thru Oregon to California the Cascade Range is composed largely of volcanic rocks. These include rhyolite, andesite and basalt,—the last predominating. Much of the material is Eocene and much probably of Miocene age, like the flows of the Columbia Plateau on the east. The recent flows, cinder cones, and great volcanic piles such as Mts. Shasta and Hood prove, however, that much of the material is of comparativly recent age.

In the Sierra Nevada, Tertiary deposits are relativly thin. They consist chiefly of Miocene sand and gravel deposited in shallow old valleys and apparently grading into the brackish-water Ione formation along the west base of the range. These Miocene gravels, which are renowned for their rich gold placer deposits, are covered by volcanic flows and breccias, chiefly basaltic but including andesite and rhyolite. Miocene deposits are not recognized in the southern part of the range.

Among Quaternary deposits glacial drift is widely distributed but only in the form of local moraines. Those around Mono Lake in California are remarkably conspicuous. Owing to the comparativly rapid erosion to which the mountains have been subjected in recent times, but little alluvium has accumulated, except in certain high mountain basins and along the lower courses of some of the streams.

Structure.

Structurally it is convenient to recognize three divisions of this element, namely, the Sierra Nevada, the southern Cascade Mountains and the northern Cascade Mountains.

Sierra Nevada. The older rocks of the Sierra Nevada have been intensely folded and largely metamorphosed.

This mass comprises Paleozoic and early Mesozoic terranes. Initially, these rocks consisted of bedded sediments and volcanic flows, the sequence being interrupted by a few erosion unconformities. In consequence of the post-Jurassic disturbance, they now stand on edge in isoclinal folds, the axial planes of which are nearly vertical. The trend-lines of the folds vary from northwest to north-northwest. Overthrusts seem to have been recognized only in northern California, where Diller finds the beds thrust up toward the northeast. Slaty cleavage, which has been induced in most of the argillaceous beds, is generally parallel to bedding, but locally departs from it. In some places the cleavage is obviously parallel to the periphery of a batholith.

Into this closely folded mass great bodies of igneous rock have been intruded in such a manner as to largely replace the folded rocks. Among these intrusions there is great variety of size, form and composition. The largest are batholiths with subsidiary stocks. In some places the batholiths are compound, a succession of magmas of slightly different mineralogical composition having been intruded successivly in the same region. The largest bodies are those of the granodiorite, which appears to have been the latest of the greater intrusions. In addition to, and probably cognate with, the batholiths, are stocks and dikes of all sizes and shapes. Along their contacts with the bedded series, the intrusions have produced the familiar phenomena of static metamorphism, but the intrusions themselves do not generally show the effects of subsequent alteration.

The younger rocks, which play but a small part in the formation of the Sierra Nevada, generally lie flat or, as in the case of the Cretaceous rocks, are very gently flext.

As a whole, the Sierra Nevada appears to be a tilted block, broken on the eastern side and gently inclined toward the west. The breakage has taken place not along a single fault but along a zone of fracturing,—the individual faults being inclined steeply northeastward. Here and there a fault passes into a monoclinal fold, as noted

by DILLER[1] near Honey Lake. The greatest displacement along this zone of faulting seems to be in the region of the southern Sierra Nevada, where Mt. Whitney overlooks the deep depression of Owen's valley. That the block is still rising along this fault zone is indicated by the earthquake-forming dislocation of 1872 (see p. 162).

Southern Cascade Mountains. From northern California to southern Washington the Cascade Mountains reveal scarcely any rocks older than the Tertiary lavas. In a few small localities where the more ancient formations appear, it is clear that they have the same structure as in the Sierra Nevada. It appears therefore that the younger volcanic series is to be regarded merely as a covering beneath which the Sierran structures persist northward.

The Tertiary beds consist almost exclusivly of flows, with beds of tuff and breccia piled one upon the other to a great thickness. The older flows (Eocene?) have been slightly folded. Along the east side of the range the zone of faults continues from northern California into southern Oregon, but apparently it does not extend far northward.

Northern Cascade Mountains. In a general way the structure of the Cascade Mountains in Washington resembles that of the Sierra Nevada, with the exception, however, that the Tertiary and Cretaceous rocks are somewhat folded and invaded by intrusions. In a broad way this part of the range, like that immediately south of the Columbia, seems to be merely a geanticline rather than a fault block. The structure of the older rocks is regarded by SMITH and CALKINS[2] as in general that of a synclinorium, but evidence is still too meager to make this certain.

The older series of rocks, resting unconformably beneath the Comanchean strata, are intensely deformed like those in California. They stand in closely appresst folds, the axial planes of which are nearly vertical and trend generally north or northwest. Locally the beds have been much crumpled and twisted, and the folds themselves are almost obliterated by the prevalent schistosity.

Again as in California, this highly folded mass has been intruded by several batholiths of granitic rocks. It is significant also that serpentine and gabbro are here found intruded by large masses of granodiorite, the relations being similar to those in the Sierra Nevada. R. A. DALY[3] suggests that the great compound batholith of the Okanagan region near the 49th parallel has had a long history, for intrusions have been made at the same point in Carboniferous (?), Jurassic and Miocene times.

With the older rocks the structural similarity between the northern Cascades and Sierra Nevada ceases, for here even the Cretaceous and Tertiary beds are deformed. The Comanchean strata are separated from the underlying rocks by well markt angular unconformities. These beds have been closely folded, and locally they have slaty cleavage. From the unfortunate circumstance that Eocene and Comanchean strata do not appear to have been found in contact with each other, it is not known whether the lower Cretaceous has suffered more deformation than the Tertiary. All that can be said, is that the Comanchean rocks are more deformed in latitude 49° N. than are those of the Eocene 200 kilometers farther south.

In the Snoqualmie district of central Washington the Eocene and even early Miocene beds are moderately folded and locally stand on edge. These folds have a northwesterly or even westerly trend, apparently not agreeing with the older north-south post-Jurassic flexures, but rather with those of the Olympic Range. All of the rocks up to and including the early Miocene have been intruded there by a batholith

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[1] DILLER, J. S., Geology of the Taylorsville Region, California. U. S. Geol. Survey, Bull. 353, 1908.

[2] Op. cit.

[3] DALY, R. A., The Okanagan Composite Batholith of the Cascade Mountain System. Bull. Geol. Soc. of Am., vol. XVII, 1906, pp. 329—377.

of granodiorite, which has severely metamorphosed the Tertiary sediments around its borders.[1] On the eroded surface of both folded sediments and batholith, later Miocene lavas rest in broad open folds.

Upon these several systems of rocks, each less folded than the one beneath, have been superposed the late Tertiary and Quaternary lavas, erupted chiefly from such volcanic centers as Mts. Baker, Rainier, and others. Only these, together with the glacial and alluvial deposits of the Quaternary, have escaped noteworthy deformation.

Geologic history.

Broadly speaking, the known history of this province may be divided into three periods; — the first, a long era, ranging from Paleozoic and perhaps earlier time to the close of the Jurassic, during which there was sedimentation, largely beneath the sea, with intermittent volcanic activity; the second, a brief epoch of intense deformation and igneous intrusion; and the third, a subsequent era in which erosion has fashioned the surface, except where local and largely non-marine sediments were laid down. This time was markt by widespread volcanic eruptions. For the northern part of the Cascade-Sierra system, a second epoch of deformation and intrusion must be added in the midst of the Tertiary period.

The pre-Comanchean Era. The record of the earlier periods is known almost exclusivly from the studies of Whitney, Diller and others in northern California. In Washington hardly more than traces have been workt out. During the Paleozoic and early Mesozoic periods the whole region seems to have been generally subject to sedimentation. That the sediments were laid down largely under the sea is indicated by marine fossils at many horizons. In many series, however, the sediments and fossils are such as to indicate terrestrial deposition. The sediments which accumulated during this vast lapse of time are predominantly clastic, comprising alternate beds of conglomerate, sandstone, and shale, with some limestone. This may be taken to imply the proximity of a land body, and, since limestone grows more abundant toward the east, it seems probable that the land mass lay west of the present mountains.

There were many volcanic eruptions all thru this long sedimentary era,—especially before the Silurian (perhaps pre-Cambrian) and early in the Triassic. The products of these eruptions were flows, breccias and tuffs, and like the more recent Tertiary lavas, they were rhyolitic, andesitic, and basaltic. Some of the eruptions appear to have been sub-marine, while others were undoubtedly terrestrial.

That the region emerged from the sea now and then, and was subject to erosion, is indicated by several unconformities. Of these emergences, the best known is that which took place in northern California about the end of the Carboniferous, permitting the Triassic and Jurassic beds to be laid down unconformably on the Carboniferous rocks. So far as known the emergences were not accompanied by noteworthy deformation, altho in consequence of the intense post-Jurassic disturbance the effects of such foldings would now be difficult to detect.

The Pacific Mountain Revolution. The great orogenic disturbance at or near the close of the Jurassic made itself felt thruout the entire extent of the Pacific coast of the United States as well as far into Canada and Mexico. The cause of the disturbance was evidently a tangential thrust, which perhaps originated in the Pacific basin. The movement squeezed the older strata into closed upright folds of northwesterly trend, and simultaneously the more susceptible beds were converted into schists. At the time of or soon after this deformation, vast bodies of moderately acidic magma invaded the crumpled mass from beneath, apparently absorbing large volumes

[1] That this is not an exceptional occurrence is indicated by the fact that Daly has found a Tertiary granitic batholith on the 49th Parallel farther north.

of the sediments and crystallizing in their room in the form of batholiths and subsidiary intrusions. That surface volcanic activity accompanied the rise of such great quantities of molten matter may well be believed; and yet no traces of the effusiv products have been recognized.

It is generally supposed that the surface results of this disturbance must have been a series of high mountain ranges with which were perhaps associated great volcanic cones.

The post-Jurassic Era. The conspicuous angular unconformity which separates the Jurassic from all younger rocks shows clearly that the deformation soon ceast and its resultant structures were as quickly mastered by erosion. From many facts it is clear that the mountain ranges born of the folding must have been largely planed off before the Comanchean sediments were laid down,—the roofs of the post-Jurassic batholiths being uncovered and the granites themselves deeply eroded in the process. The record of deposition complementary to this deep erosion may be sought in the enormously thick deposits of the Shasta and Pesayten series of Comanchean age. There is no evidence that the Sierra Nevada was actually submerged by the waters in which the sediments were deposited, but there can be little doubt that the site of the Cascade range was in large part covered at that time,—another reason for believing that the mountains due to folding were soon swept away. In the Cretaceous period similar relations seem to have prevailed, with important local differences; the sea covered part of the northern Sierra Nevada, but perhaps was excluded from the Cascades.

Conditions do not appear to have been materially changed in the Sierra Nevada during the Eocene period. J. S. Diller reaches the conclusion that the effect of long continued erosion had been sufficient by this time to reduce the northern Sierra Nevada and the adjacent Klamath Mountains to a peneplain. R. A. Daly holds the hypothesis that in the Northern Cascades the Cretaceous rocks were subjected to further folding just before the Eocene period. It is at least true that rapid sedimentation began in central Washington in the Eocene, the deposits being laid down partly in lakes but no doubt largely by rivers. There is evidence of intermittent warping with occasional erosion of the early Tertiary deposits; and temporarily an epoch of volcanic activity resulted in the thick succession of basaltic flows and rhyolitic deposits interbedded with the Eocene sediments of west central Washington and Oregon. At least locally in the northern Cascades, these events were prolonged into the early Miocene by the accumulation of terrestrial sediments upon an eroded surface of Eocene beds.

The middle of the Miocene period seems to have been a time of widespread deformation in western America. Altho lying between the two deformed districts of the Basin and Coast Ranges, the Sierra Nevada, as a resistant unit, seems to have escaped deformation. Farther north in Washington, however, the Cascade region yielded to the compressiv forces, so that the Miocene and older beds are moderately folded; and, as at the close of the Jurassic period, the folding was accompanied by the intrusion of siliceous magma which cooled in the form of small batholiths of granite.

The deformation in the Cascade Mountains was succeeded by a period of erosion long enough to permit the truncation of the new structures. Upon this irregular surface were then poured out the succession of flows of liquid basalt and more viscous andesite which largely mantle the surface of the Cascade highlands. There was corresponding volcanic activity in Oregon and northern California. During the eruptions, and particularly just after them, sediments were deposited along both flanks of the Cascade Range in lakes and rivers, and with them were intombed leaves of plants which imply a moderate climate.

By this time apparently the Sierra Nevada had been reduced to comparativly low relief; and there, in the broad valleys, gravel and sand, with particles of gold from

the older slates, were strewn by rivers descending into the central valley of California. These river sediments were soon buried by sheets of volcanic breccia and basaltic flows, largely from the northeast.

Events in the Pliocene period have not been workt out with clearness. According to Willis and Smith[1], the northern Cascade Mountains remained so quiet during this period that they were reduced to a peneplain. Volcanic eruptions doubtless continued in California and Oregon and it may be supposed that the great modern volcanic cones of the region began their growth at this time, if not before.

Le Conte[2] has urged the view that the end of the Pliocene was markt by broad uplift and dislocations generally thruout western United States. To this movement is assigned the upward warping of the entire Sierra-Cascade system and the breaking of this arch in the fault zone along the east base of the Sierra Nevada. As a result of these changes of level the Quaternary period witnest the cutting of many deep canyons of which the famous Yosemite valley and the gorge of the Columbia may be taken as examples. Late in the Quaternary period the mountains were glaciated from one end to the other, and there is also evidence of an earlier epoch of ice work.

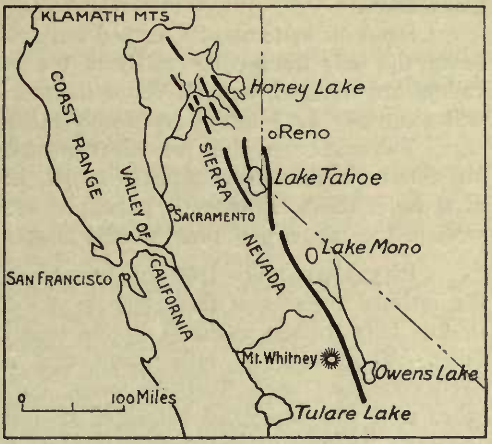

Fig. 50. Map of portions of California and Nevada showing lines of Quaternary faulting on the east side of the Sierra Nevada. (The faults are represented by heavy black lines.) (After J. S. Diller, U. S. Geol. Surv.)

Since glaciation the events have been few and of but small importance. Volcanic activity has subsided so that most of the cones now appear to be essentially extinct. Some of them may, however, be merely dormant, for Mt. Baker northeast of Seattle is said to have ejected ashes in 1842, and a very recent lava flow on the slope of Mt. St. Helens is reported to have issued in 1841.

Physiography.

Topography. In general the Sierra Nevada-Cascade Range is a broad uplift deeply dissected by short valleys descending both east and west. In California the uplift is distinctly asymmetrical,—the slope on the west being gentle, while that on the east is steep. It is generally agreed that this is a fault block in its larger outlines. The volcanic cones, both large and small, which form the more conspicuous features of the range from California northward, are purely constructional and must be considered apart from the general topography of the region. Only three rivers transect this range: the Columbia, the Klamath, and the Pitt. Of these the first is doubtless antecedent, having held its course while the range was being uplifted across its path. The histories of the Klamath and Pitt Rivers, the last being a branch of the Sacramento, are not yet well known; but it seems probable that their histories are unlike that of the Columbia. In the Sierra Nevada, flat-topt interstream divides which decline gently westward are separated by deep canyons. Along the crest of the range, especially above altitudes of 2500—3000 meters, there is a sea of rugged peaks separated by

[1] Op. cit.

[2] Le Conte, J., Critical Periods in the History of the Earth, Univ. of Cal. Bull. Dept. Geol. vol. I, pp. 313—336, 1895.

glacial cirques in which lie many alpine lakes. The higher peaks are strewn with perennial snow fields and even small glaciers. Near the southern end of the Sierra Nevada, there appears a modification of the topography which seems more related to the southern Coast Ranges, i. e., ranges with escarpments on the north and east, bounding irregular alluvial basins.

Disregarding the recent volcanic cones, most of the peaks in the Cascade Mountains rise to a common level, 2000 to 3000 meters above sea level. They have the rugged sculpture of deeply glaciated mountains and the heads of the valleys contain many lakes.

Dendritic systems of V-shaped canyons descend both east and west,—the Columbia being the only transecting valley in the region. As in California, the slopes of the valleys are terraced, and no doubt the more recent erosion histories of the two regions will some day be found to be closely related.

Volcanic cones are the most imposing topographic features of the range, from Mt. Shasta in northern California to Mt. Baker near the 49th parallel. The grandeur of some of these volcanoes is enhanced by the fact that they rise from the open plateau west of the range, and thus present almost their full height to view.

Physiographic Development. Nearly all students of the region agree that the inclined surfaces of the spurs in the Sierra Nevada represent a former peneplain or low hilly surface produced by the long continued erosion of the post-Jurassic mountains. There can be little doubt that much of this erosion was accomplisht in Cretaceous and early Tertiary times, but there is some difference of opinion as to whether it was completed before or after the Miocene. According to Diller[1], some of the early Tertiary valleys were parallel to the general trend of the range or, in other words, adjusted to the folded structures, and their wide bottoms were afterward filled with gravel and lava.

At the northern end of the range in Washington, the facts are less clear. On account of the pronounced deformation in the Miocene it seems impossible that any pre-Miocene surface remains in recognizable condition. B. Willis[2] regards the accordant summits of the Cascades as the last remnants of a plateau, this plateau having once been a peneplain formed at a lower elevation. If this view is correct, the plain must be approximately of Pliocene age, since it truncates folded late Miocene sedimentary and volcanic deposits. R. A. Daly[3], on the other hand, urges that the accordant summits may be due to other causes than planation.

In the Sierra Nevada strong uplifts with gentle warping greatly changed the conditions of erosion about the end of the Tertiary period. The Sierra Nevada block was raised on the east and tilted westward. This movement revived and gave great strength to the short rivers flowing down the western slope. They quickly sank canyons into the old surface leaving remnants of it in the form of flat-topt dividing ridges. Some of these valleys are now more than a thousand meters deep. The old longitudinal drainage courses of the Tertiary period were not only disturbed by the gentle warping of the surface, but were soon dismembered by the short westward flowing streams. The old valleys may still be traced by means of a succession of gravel filled saddles in the high flat-topt spurs. The Tertiary peneplain, now deeply dissected by short valleys, is recognized also in southern Oregon.

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[1] Diller, J. S., Geology of the Taylorsville region, California. U. S. Geol. Survey, Bull. 353, 1908.

[2] Op. cit.

[3] Daly, R. A., The Accordance of Summit Levels among Alpine Mountains: the Fact and its Significance. Jour. of Geol., vol. XIII, 1905, pp. 105—125.

Lawson[1] produces evidence to show that in relativly recent geologic times the rocks near the southern end of the Sierra Nevada have been broken along intersecting faults, thus giving tilted orographic ridges and triangular basins. The ridges are gasht by short ravines, while the basins are floored with alluvial fans. The main streams of the region enter and leave these basins thru canyons, and in general are quite out of adjustment.

In northern California and Oregon volcanic cones have been built upon the surface of the old plateau. At the same time many of the valleys have been filled with volcanic debris, and even the recent canyons have here and there been obstructed by lava flows.

Glaciation, which occurred perhaps twice in the Pleistocene period, made important changes in the topography of the entire range. In California the glaciers descended the larger valleys almost to the edge of the mountains. Thru the process of cirque formation, the peaks were sharpened and the valley heads deepened. The upper courses of some of the rivers, like the Merced, have been deeply excavated by the glaciers. To this process and to the massiv jointed granitic rock is generally ascribed most of the wonderful scenery of the Yosemite valley, where nearly vertical cliffs hundreds of meters in height are interrupted here and there by lofty waterfalls.

Farther north in Washington the glaciers descended to within 300 meters of sea level on the east slope, and spread out into Puget Sound itself on the west. But few ridges are free from the effects of glaciation. Inasmuch, however, as most of the Cascade peaks are lower, the topography is on the average no more rugged than that of the Sierra Nevada. Altho so young, even the great volcanic cones have been more or less scarred by late Quaternary glaciers, the descendents of which are now continuing the work.

As in other parts of the West, the changes which have taken place since what is generally regarded as the end of the glacial period have been remarkably small. They may best be considered in connection with the Coast Ranges.

Seismicity.

The Sierra Nevada-Cascade region as a whole is subject to more frequent earthquakes than any region east of it. In the Cascade Mountains, however, earthquakes seem to be relativly infrequent. It is in California, and particularly along the east base of the Sierra Nevada, that many earthquakes, some of them destructiv, have been recorded. One of these, the Owens valley earthquake of 1872, has already been mentioned (p. 162).

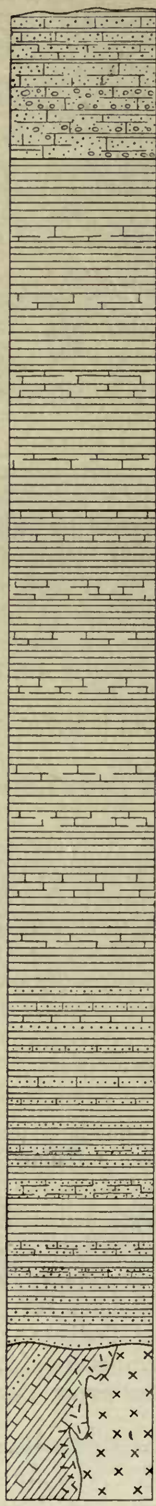
California Valley.

General.

From Alaska to the Gulf of California there extends a long series of structural depressions, one of which is the great central valley of California. It is hemmed in on all sides by mountains,—the Coast Ranges on the west, and the Sierra Nevada on the east,—and thru the Coast Ranges it has a single outlet at San Francisco Bay. On account of its relativly dry climate, it is not covered with forest; but before it was converted into rich farms and orchards, it was an open grassy plain, floored with rock waste and fine soil washt down from the adjacent mountains.

The rocks within the basin itself are chiefly of Tertiary or Quaternary age, and largely unconsolidated. Along its borders, however, older rocks, which underlie the valley at greater depths, are exposed. Altho the older terranes are much deformed, as

[1] Lawson, A. C., The Geomorphic Features of the Middle Kern. Univ. of Calif. Bull. Dept. Geol. vol. IV, No. 16, 1906, pp. 397—409.

Per.	Div.	Formation.	Strata.	M.	Description.
Cretaceous (upper Cretaceous).		Chico.			Shale with thin sandstone.
				300	Sandstone and shale (*Inoceramus whitneyi* and *Pachydiscus Newberryanus*).
				150	Massiv sandstone.
				150	Conglomerate and massiv sandstone (*Thetis anulata, Chione varians, Tellina Ashburneri*, etc.).
				300	Conglomerate, sandstone and shale (*Pecten operculiformis, Trigonia leana, Anchura californica*, etc.).
Comanchean (Lower Cretaceous).		Horsetown.		2300	Shale with interbedded sandstones (*Nemodon vancouverensis*).
		Knoxville.		1500	Shale with calcareons layers (*Belemnites impressus* and *Lytoceras batesi*).
				1500	Shale with calcareons layers (fossil ferns and other plants).
				900	Shale and shaly sandstone with calcareons layers.
				1100	Shalo and shaly sandstone (*Aucella piochii*).
				450	Shale and thin sandstone.
		— Unconformity. —			
Pre-Comanchean.					Jurassic and older rocks, highly folded and more or less metamorphosed. Intruded by granodiorite, gabbro and serpentine.

SECTION SOUTHWEST OF RED BLUFF, CALIFORNIA.[1]

[1] Adapted after J. S. Diller and T. W. Stanton, 1894.

in the mountain ranges adjacent, the Tertiary and later beds lie almost horizontal except where they have been folded up into the Coast Ranges on the west.

Stratigraphy.

In general the stratigraphy of the valley is simple, altho complex and not well understood in detail. The component sediments are chiefly clastic and probably in large part terrestrial, altho interbedded with marine deposits. In age they range from Comanchean to Recent, but the sequence is interrupted by local unconformities. The beds along the east side of the valley do not correspond lithologically with those on the west, a fact doubtless to be ascribed to ordinary changes in the sediments perpendicular to the coast line.

Along the eastern border of the valley, a succession of sandstones with many conglomerate beds and much shale rests unconformably upon the deformed older rocks. The lowest of these formations, the Chico, is of upper Cretaceous age, and in part marine. Higher beds in the sequence represent Eocene and Miocene,—the latter apparently a brackish water deposit. Unconformably over the Ione (Miocene) sandstone have been strewn fragmental volcanic deposits,—chiefly rhyolitic and andesitic,—together with river gravels. These correspond to the similar formations in the adjacent Sierra Nevada and they do not extend far west of it. Probably related to these volcanic materials is the extinct and now deeply eroded volcano in the midst of the valley near Marysville[1], which is composed of similar rocks and in the process of growth disturbed the early Tertiary sediments.

It is generally believed that the Quaternary deposits of sand, gravel and loam, which cover nearly the entire surface of the valley, are very thick. Well borings have penetrated them to depths of more than 700 meters, without attaining the base. The sediments have been brought down by streams chiefly from the Sierra Nevada, and on that acccount are coarser along the eastern border and finer near the axis of the valley. A part of the Quaternary sediments was doubtless deposited in a temporary arm of the sea, but the superficial layers are evidently terrestrial.

Along the western border of the valley the sedimentary beds are much thicker, —estimates exceeding 10000 meters having been made by several students of the region. The sequence is also more comprehensiv, including beds ranging from the Comanchean to the present. It is probable that with the exception of the late Tertiary and Quaternary deposits the beds are largely marine. Since they have been upturned in the Coast Ranges it is more convenient to describe them in that connection (see pages 192—196).

Structure.

The California Valley is apparently a downwarp, or geosyncline. Its foundation is a mass of highly folded rocks breacht by granitic intrusions, and planed off by erosion. Upon this rests a thick series of sedimentary rocks which dips gently toward the axis of the valley except where it has been much crumpled along the western border. The downwarp itself is now bottomed with bedded sediments, including a subordinate amount of volcanic tuff and breccia. The sediments are chiefly alluvial fan deposits derived from the mountains on either side; hence the individual beds are wedge-shaped or lenticular, and lithologically variable. Around the Marysville volcano in the Sacramento valley, where the rising of the viscous andesitic magma has upturned the Eocene and later strata in the form of a dome, is afforded the only sample of the underlying Tertiary beds which is to be found anywhere in the middle of the valley.

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[1] Lindgren, W., and Turner, H. W., Marysville, Cal. folio, No. 17. Geol. Atlas U. S., U. S. Geol. Survey, 1895.

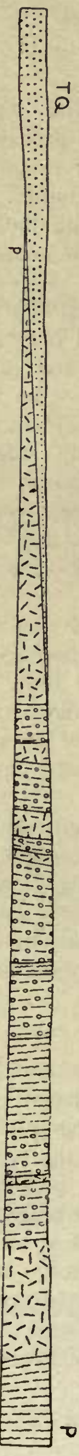


Fig. 51. Profile of the east edge of the California valley near Sacramento: TQ, Tertiary and Quaternary sediments; P-P, Tertiary peneplain truncating highly folded beds of Jurassic and older rocks of the Sierra Nevada. (After W. Lindgren, U. S. Geol. Surv.)

Geologic history.

So far as known the history of this region prior to the end of the Jurassic period differs in no essential respect from that of the Sierra Nevada. Diller[1] suggests that the trough was made during or at the beginning of the Comanchean period and that the thick sediments of that period were deposited in such a depression. On apparently better grounds Ransome[2] dissents from this view, advancing the opinion that the region was subject to sedimentation along an open coast during the Comanchean and Cretaceous periods and on into the Eocene. By the folding of the Coast Ranges along the west in the Miocene period, the valley acquired very nearly its present form. This change consisted merely in the raising of a crumpled barrier on the west and not in the deformation of the strata within the valley proper.

There is some difference of opinion as to conditions in late Miocene and early Pliocene time. There is reason to think that the valley temporarily held a broad arm of the sea, but it is improbable that this was the prevailing condition, as once supposed. Judging from the plants in the Ione formation, the climate at that time must have been subtropical. Believing that the Sierra peneplain is of Pliocene age, Ransome is of the opinion that the California valley was essentially a continuation of that plain and must have been very close to sea level at the time. Later, near the close of the Pliocene, came the great disturbance to which most of the existing topographic relief of the West is due. The effect on the California valley is thus described by Ransome:

"But with the post-Pliocene elevation of the crest of the Sierra, and with the gradual upward diastrophic movement of the Coast Ranges during Pleistocene times . . . . . . the valley became closed in by mountains as we find it at the present day, and became a definite and well bounded area of sedimentation or deposit. The movements which brought about this condition are, as far as we know, still going on. The great orographic block of the Sierra Nevada is still being tilted up at a higher angle, and the Coast Ranges (with perhaps one or more local exceptions) are still emerging from the sea. All through Pleistocene and recent times, the streams flowing down from the Sierra, and from the eastern slope of the Coast Ranges, have been pouring detritus into the deepening valley, depositing the coarser materials in broad alluvial fans, and carrying the finer silt farther out, to be spread over the plain in flood seasons."

Apparently sedimentation and subsidence have been almost balanced for a considerable period of time. Recently the sea, by invading San Francisco Bay, has gained a slight advantage.

Physiography.

The great elongate basin is in general a monotonous plain, nearly flat in the center, with very gentle slopes rising to the mountains on either side. On the east the long slope of the Sierra Nevada ascends gradually, but on the west the Coast Ranges stand out as a rugged chain (see Fig. 48). It is generally agreed that the former is a gently tilted

[1] Diller, J. S., and Stanton, T. W., The Shasta-Chico series. Bull. Geol. Soc. of Am. vol. V, 1894, pp. 435—464.

[2] Ransome, F. L., The Great Valley of California: A Criticism of the Theory of Isostasy. Univ. of Cal. Bull. Dep. Geol., 1896, vol. 1, No. 14, pp. 371—428.

and dissected peneplain of Miocene or Pliocene age, while the latter are due to Tertiary or later folding and faulting.

From the mountains on each side streams have built alluvial fans out into the valley. Since the rivers from the east are much larger and more powerful, their fans are far more extensiv than those from the west; and they have thus forced the longitudinal rivers west of the true axis of the depression. Near the mouths of the canyons the individual fans may consist of coarse material and have perceptible slopes, but out in the middle of the valley the slopes are nearly flat and the material is fine.

The lateral streams unite in the middle of the valley to form three distinct systems. Those in the north make the Sacramento River, and those in the central portion the San Joaquin. These two unite and enter the ocean at San Francisco Bay. In the southern part of the valley the growth of a large alluvial fan has blockaded the drainage, so that some of the streams empty into an isolated basin containing several lakes. On account of the semi-arid climate these lakes do not overflow the very low divide. Along the main streams in the bottom of the valley there are extensiv swamps thru which the rivers wander in wide swinging curves. Along the east side of the valley, and to a less extent on the west, there are terraced flat-topt uplands representing older deposits dissected by the modern streams.

Seismicity.

The California Valley is subject to frequent earthquake shocks, some of which have been disastrous. Since, however, these disturbances seem not to originate in the valley itself, but in the adjacent Coast Ranges, a consideration of this topic may be deferred (see p. 200).

Puget Trough.

General.

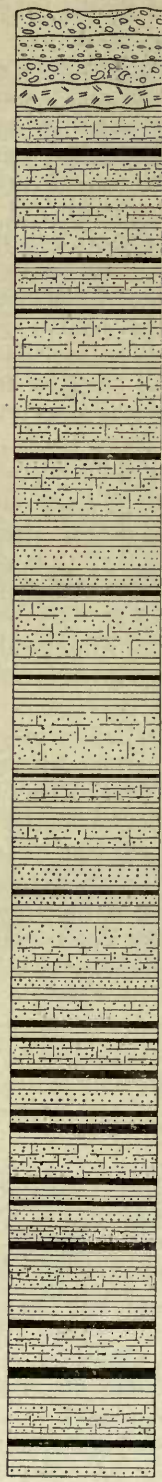
The Puget trough is a broad downwarp, or geosyncline, between the Cascade Range on the east and the Olympic and Oregon coastal ranges on the west. It is analogous to the great valley of California and probably similar in general origin. It is not, however, like it in detail, and is neither so simple nor so symmetrical. The two depressions are separated by the dissected plateau of the Klamath Mountains.

In stratigraphy and the details of its history the Puget trough does not closely resemble the California valley. As in the Cascade Mountains farther east, all but the most recent beds have been folded. The bottom of the valley is not smoothly floored with waste but has been dissected into a hilly lowland, the northern part of which has been glaciated. Being subject to a cool moist climate, it is normally covered with a dense forest which has contributed to make the study of the geological features more difficult.

Stratigraphy.

On either side of the Puget trough intensely folded and metamorphosed ancient rocks, probably not younger than Jurassic, are exposed here and there. These doubtless underlie all of the depression at considerable depths.

Upon this basement rests a thick series of sedimentary beds. Comanchean and Cretaceous sandstone and shale have been found at intervals along the flanks of the valley, but the sediments most widely exposed at the surface are of early Tertiary age, — probably both Eocene and Oligocene. Such studies as have been made reveal a thickness of 3000 to 4000 meters of arkose sandstone and shale, with coal seams scattered especially thru the lower portion. Altho in Oregon this series has yielded a few marine fossils, in Washington only *Unios* and plants have been found. The plants of the lower beds include large palms, figs *(Ficus)*, and other subtropical types,

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.		Post-glacial.			Swamp deposits; valley alluvium; silt and sand along stream courses.
		Late glacial. Vashon glacial drift.		?	Glacial till with associated stratified deposits of gravel, sand and clay.
		Interglacial. Unconformity.		?	Sand, gravel and clay.
		Early glacial. Unconformity.		?	Admiralty till and stratified glacial deposits.
Tertiary.	Miocene?	Pyroxene andesite. Unconformity.		?	Flows, tuff and breccia.
	Oligocene. - ? - Eocene.	Puget.		3000±	Gray arkose, sandstone, shale, and carbonaceous shale with many coal beds. (Base of formation not exposed.)

SECTION NEAR TACOMA, WASHINGTON.[1]

[1] After B. Willis, U. S. Geol. Survey, 1899.

while in the upper portion a flora including the birch *(Betula)* and chestnut *(Castanus)* prevails. Into these beds have been intruded basic dikes and sills.

Of Miocene sediments only traces have been found. Near Puget Sound certain beds of greensand with marine fossils are apparently Miocene. Lavas and tuffs, probably of middle Tertiary age, enter the valley from the west, but are essentially a part of the great Cascade volcanic series.

The northern part of the Puget trough is completely covered with glacial drift, but in Oregon there are merely local moraines from valleys in the Cascade Mountains. Near Tacoma, Wash., WILLIS[1] found two layers of glacial drift separated by interglacial sands and an unconformity. The bottoms of the valleys are floored with recent alluvial deposits largely of glacial derivation.

Structure.

Structurally, the Puget trough appears to be much like the northern Cascade and Coast Ranges, except that it is a geosyncline whereas they may be regarded as geanticlines. There, as well as elsewhere along the Pacific slope, the pre-Comanchean rocks were intensely folded, largely metamorphosed and intruded by a variety of granitic rocks. They are but rarely exposed. The enormously thick Cretaceous-Eocene succes-

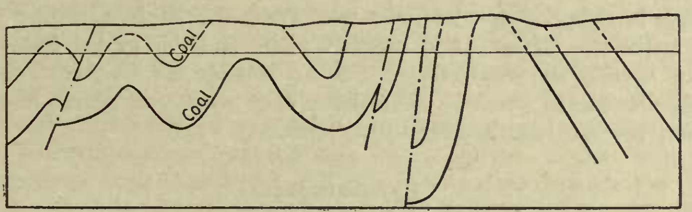


Fig. 52. Profile east of Tacoma, Wash. showing folded and faulted coal beds in the Puget series (Eocene?). (After B. WILLIS, U. S. Geol. Surv.)

sion has been comprest into rather steep folds, which are not, however, isoclinal. In the coal mining districts overthrusts have been found associated with the folds, but elsewhere sufficiently detailed studies have not been made. The general trends of these folds are east of north in the southern part of the trough, but distinctly northwest in the vicinity of Puget Sound. In some parts of Oregon great sills of diabase, some of them more than 100 meters thick, have been intruded between the beds; and thruout the district dikes of diabase and pyroxenite are not uncommon.

The late Miocene sediments and lavas and all the Quaternary formations rest unconformably upon the deformed strata and are themselves nearly horizontal.

History.

Altho less well known, the history of the Puget trough probably resembles in a general way that of the California valley,—with, however, important differences. After the intense folding, near the close of the Jurassic, the whole region was deeply eroded and later covered more or less completely by the thick coastal sediments of the Comanchean. There is evidence to indicate that these deposits emerged at the close of that period and were eroded. It is held by DILLER and others that there was even considerable deformation and vulcanism in connection with this emergence.

In the early part of the Tertiary period sediments were deposited rapidly. At that time the Coast Ranges probably did not exist, and there is much to indicate that

[1] WILLIS, B., and SMITH, G. O., Tacoma, Wash., folio, No. 54, 1899, Geol. Atlas U. S., U. S. Geol. Survey.

streams from the east built up a broad coastal plain along the Pacific ocean. From the testimony of the numerous coal seams and the unweathered character of the constituents of some of the sandstones, it may be supposed that the region was heavily covered with vegetation and enjoyed a moist climate. The older floras are thought to indicate subtropical conditions, but those higher in the series imply a temperate climate.

At or near the close of the Miocene period, the whole region, from Oregon to British Columbia, was comprest and the existing beds folded. This disturbance gave birth to the Coast Ranges, and with the erection of this barrier the Puget trough may be supposed to have originated. Since all the folds are bevelled to a relativly plane surface, it is clear that long and effectiv erosion followed the folding. Soon afterward the region must have been temporarily invaded by an arm of the sea in which the supposed Miocene beds were deposited. Unlike the valley of California, the down-warp does not seem to have been deeply filled with river deposits.

In the later part of the Tertiary period andesitic and dacitic lavas were poured into the region on the southeast, but only locally have they left prominent effects.

In the Pleistocene period a great glacial lobe descending from the north, and augmented by ice-tongues from the mountains on the west and east, filled Puget Sound and the northern part of the trough with a great piedmont glacier, which pusht southward almost to the Columbia River. Much smaller glaciers issued from the Cascade Range in Oregon and left moraines along the borders of the valley. Thin deposits of fossiliferous marine clay, together with scattered glacial boulders evidently transported by floating ice, imply that the ocean invaded the Columbia and Willamette valleys, during the glacial period. There have been other changes of level during and since glaciation but they are imperfectly understood.

Physiography.

In general the Puget trough is a long depression, from 25 to 200 kilometers wide, flankt on either side by mountains 1500 to 3000 meters high. The northern end is partly submerged, and both mountain barriers are broken where the Columbia River enters the Pacific Ocean. In markt contrast to the California valley, the surface of the Puget trough is generally hilly, with narrow alluvial flats along the streams. The thick covering of forest serves to render the contrast even stronger. The rock hills in the north are generally tabular and intersperst with steep-sided valleys,—Puget Sound being merely a submerged system of these valleys, the bottoms of which lie as much as 200 meters below sea level. In Oregon rounded hills and wide valleys imply more advanced maturity.

The series of tabular hills seems to be part of an old peneplain which bevelled the folds of the early Tertiary rocks. Presumably it is of the same age as the similar plain in California which is of either Miocene or Pliocene age. The northern valleys were probably excavated in this plain in consequence of the general elevation of the West at the close of the Pliocene period. In this respect the Puget trough differs from the California valley, which seems to have been deprest rather than elevated at that time. In details the valleys have been much modified by glaciation, having been deepened in some places and in others clogged with drift. The intervening hills have been scoured by the ice, and, south of Puget Sound, were completely buried under moraines.

At the time of glaciation or later, the valleys were invaded by the sea, so that their deeper portions are now submerged. Above sea level the disturbance of stream gradients at this time has caused the building of alluvial flats along the rivers, so that some of the valleys are now filled to depths of 100 to 200 meters.

Seismicity.

Altho the Puget Sound region is subject to occasional mild earthquakes, there is but one on record which is worthy of mention, and even that cannot be called violent. On December 14th, 1873, the lower valley of the Columbia river was severely shaken and slight damage done to houses. The cause of this disturbance it not known, but its axis seems to have coincided roughly with the Columbia valley. No recent fault scarps have been noted in the Puget trough,—a fact in harmony with the infrequency of seismic disturbances.

Coast Ranges.

General.

These ranges are only a part of a series of mountains which appear to extend along the Pacific coast from the peninsula of Lower California at least as far as southern Alaska. They are not entirely homogeneous either in structure or stratigraphy, but all seem to agree in age and general geologic features. In the United States, four parts of this chain may be discriminated:—(a) The Coast Ranges of California, (b) the Klamath Mountains, partly in California and partly in Oregon, (c) the Oregon Mountains, and (d) the Olympic Mountains, west of Puget Sound.

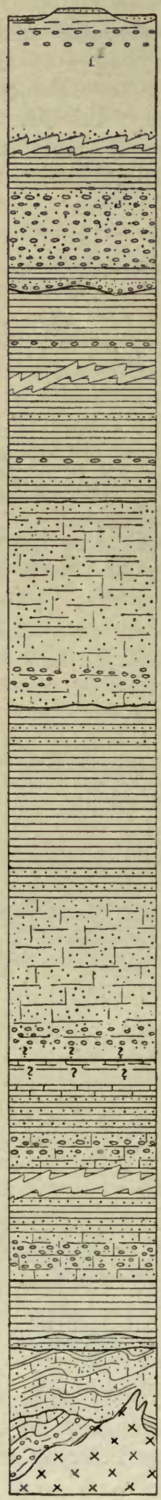
The California Coast Ranges consist of complexly folded and faulted Cretaceous and Tertiary rocks. The chain is well separated from the Sierra Nevada except where the two systems join in the mountain loop of southern California. The Klamath Mountains are geologically related to the Sierra Nevada, for the pre-Cretaceous rocks of the latter trend northwestward and reach the Pacific coast in southern Oregon. In its history the Klamath mountain group may be considered as also belonging to the Coast Range province or perhaps better still as a joining node between the Coast Ranges and the Cascade-Sierra Nevada system. The Oregon Mountains are more like the Coast Ranges of California except that the Cretaceous and Tertiary beds of which they consist have been only moderately folded. The Olympic Mountains are still very imperfectly known, because no geologist has penetrated far into the dense forests which cloak the range. Observations made along the coast indicate that it is structurally not unlike the Oregon Mountains.

The Coast Ranges are in general lower than the Sierra Nevada-Cascade system, and yet the highest of the Olympic Mountains rises to more than 2700 meters and in southern California several peaks almost attain 4000 meters. In the south the climate is relativly dry, and the forests are therefore thin and scattered. In the north, however, a moist climate induces the growth of a dense forest cover, which has in turn an important influence on the topography and has been almost the sole obstacle to geologic study. The Coast Ranges are the youngest of the folded mountains in the United States, having been made near the middle of the Tertiary period. That the deformation is not yet complete is indicated by the facts that even some of the Pleistocene beds are folded and that there are frequent earthquakes.

Stratigraphy.

The prevailing rocks of the Coast Ranges province are post-Jurassic,—altho older rocks appear at many points, especially in the south. The geology of the ranges in southern California is much better known than that of the ranges farther north, because the importance of the petroleum industry has made necessary a careful study of geologic structure and sequence.

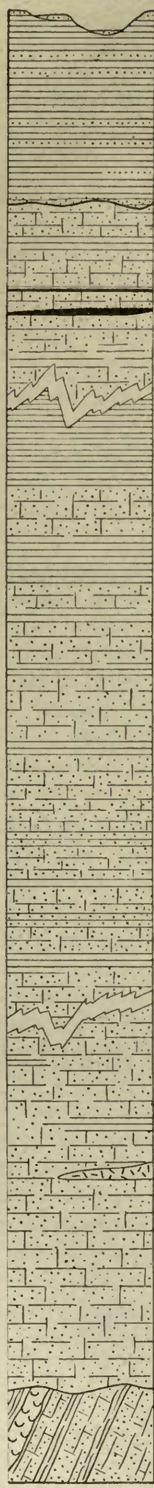
Jurassic and Older Rocks. Among the oldest rocks of the province are gneisses and schists of unknown age, which are prominent in the mountains north and east of Los Angeles, California. They are perhaps Paleozoic or even pre-Cambrian.



Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.		Alluvium.		15	Flood plain and terrace deposits, and dune sand.
		— Unconformity. —			
		Santa Clara.		150±	Coarse gravel, sand, and sandy clay of freshwater origin, locally lignitic. (Along the coast, marine sandstone and shale [Merced]).
Pliocene.		Purisima.		1600	Conglomerate and sandstone at the base, thin-bedded shale in the middle, and soft light yellowish brown sand near the top. (*Cardium meekianum, Arca schizotoma, Chrysodomus stantoni, Cryptomya ovalis, Tapes staleyi,* etc.).
Miocene.	Upper.	Santa Margarita.		100±	Coarse white sand, conglomeratic at the base, overlain by thin-bedded hard shale. *(Astrodapsis antiselli, Amphiura sanctaecrucis).*
		Angular unconf.			
	Lower.	Monterey.		1500±	Thinly laminated shale, largely diatomaceous, containing intercalated sandstone and calcareous concretionary layers. Locally bituminous and lignitic. (*Yoldia impressa, Arca obispoana, Pecten peckhami,* etc.)
		Unconformity (local).			
		Vaqueros.		800±	Coarse brown sandstone, conglomeratic near the base, locally interbedded with dark earthy shale. (*Cardium vaquerosensis, Pecten magnolia, Chione temblorensis, Agasoma sanctacruzana, Tivela ineziana,* etc.). Fine sandstone of transitional Oligocene-Miocene age at the base.
		— Unconformity. —			
Oligocene.		San Lorenzo.		750±	Fine clay shale with interbedded brown sandstone near top and bottom. (*Tellina lorenzoensis, Haminea petrosa, Turcicula sanctacruzana, Nucula dalli,* etc.).
		Butano.		650±	Massiv brown and buff sandstone with conglomerate at the base.
		(Sequence concealed).			
Eocene.		(Sequence concealed).		60±	Impure fossiliferous limestone, inclusions in diabase. *(Cidaris merriami, Terebratulina tejonensis, Pecten proavus).*
Cretaceous.	Upper.	Chico.		3000±	Thick-bedded coarse conglomerate, massiv to thin-bedded sandstone and sandy shale. (*Mactra stantoni, Arca vancouverensis, Glycymeris veatchi,* etc.)
	Lower.			230	Hard, flinty, even-bedded shale.
		Unconformity.			
		Knoxville.		30±	Conglomerate, sandstone, and dark clay shale. *(Aucella crassicollis, Amberlya dilleri).*
Jurassic (?).		Angular unconf.			
		Franciscan.		300±	Chiefly earthy sandstone in which are minor quantities of dark shale similar to the Knoxville. Contains jasper lentils and some schist.
		— Unconformity. —			
Pre-Jurassic (?).				300±	Quartz-mica schist and crystalline limestone, intruded by quartz-diorite which is cut by dikes of pegmatite and veins of quartz.

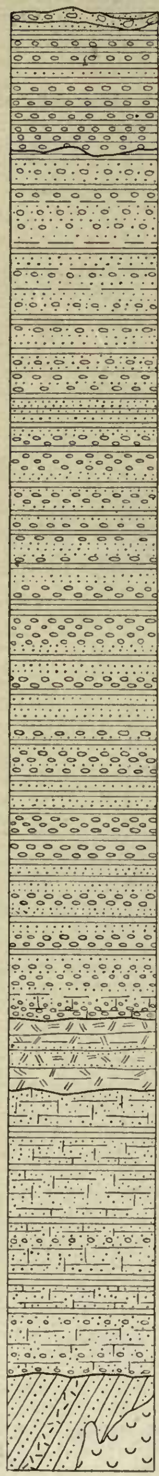
SECTION IN THE MOUNTAINS SOUTH OF SAN FRANCISCO, CALIFORNIA.[1]

[1] After J. C. Branner and others, U. S. Geol. Survey, 1909.

Per.	Div.	Formation.	Strata.	M.	Description.
Quaternary.		— Unconformity. —			River alluvium, terrace sand and gravel, and marine beach deposits
Miocene.		Empire.		150±	Dark and white shales with sandstones, containing marine fossils.
		— Unconformity. —			
Eocene and Oligocene.	Arago group.	Coaledo.			Sandstone and shale with several beds of workable coal. Marine and fresh-water shells.
		— ? —		3000	
		Pulaski.			Soft yellowish sandstone with beds of shale. Contains both marine and fresh-water shells and beds of volcanic tuff.
		— Unconformity. —			
Comanchean (or Jurassic?)[1]		Myrtle.			Gray sandstone and shale highly folded and considerably altered. Contains *Aucella*.

SECTION NEAR COOS BAY, OREGON.[2]

[1] Added by the editor.
[2] Adapted after J. S. Diller, U. S. Geol. Survey, 1901.

Per.	Div.	Formation.	Strata	M.	Description.
Pleistocene.				40	Glacial till; river sand and gravel; marine sand and clay.
		Unconformity.			
Pliocene.		Quinaielt.		670	Conglomerate and shale, with some sandstone. Fossils equivalent to those of the Purisima formation of central California.
		Unconformity.			
Miocene. Oligocene.		Clallam.		4500±	Conglomerate, sandstone and shale with abundant marine fossils, — Oligocene near the base and Miocene in the upper part.
		Unconformity.			
Eocene.		Crescent.		375	Basalt, greenish basalt tuff, and tuffaceous sand (*Venericardia planicosta* and *Turritella uvasana).*
		Unconformity.			
Cretaceous (?).				1500?	Coarse gray sandstone with zones of black shale and a little conglomerate.
Jurassic (?) or older.				?	Metamorphosed sandstone and quartzite with diabase and serpentine.

FORMATIONS OF THE OLYMPIC MOUNTAINS, WASHINGTON.[1]

[1] After R. Arnold, 1906.

In the Klamath Mountains Devonian and Carboniferous sediments have been identified by fossils. They are direct continuations of the similar formations at the north end of the Sierra Nevada. Other old rocks have been detected here and there near San Francisco but have yielded no fossils. The Franciscan formation in the California coastal ranges is believed to be Jurassic, altho not positivly identified by fossils. In general it will be observed that the pre-Comanchean rocks are much like those in the Sierra Nevada, and in the Klamath Mountains the beds have actually been traced thru.

Cretaceous to Recent Strata. A thick series of rocks (5000—8000 meters), containing Comanchean and Cretaceous fossils, rests with markt unconformity upon the Jurassic and older rocks. The strata are best exposed in the Coast Range north of San Francisco, altho they have been identified here and there farther south. The prevailing rocks are clastic sediments, chiefly alternations of shale, sandstone, and conglomerate of gray and green colors. At many scattered horizons there are beds of marine fossils, but much of the succession is barren or contains terrestrial plants. Locally it is divided by unconformities into two or three formations and is separated in the same way from the overlying Tertiary beds. In other regions there seems to be no break in the succession, and in southern California the Cretaceous passes by gradual changes into the Eocene. In the Oregon Mountains Diller[1] finds a conspicuous unconformity between the Eocene sandstone and the underlying Myrtle formation, which contains fossils like those of the Knoxville-Horsetown series of California. A succession of sandstone and shale more than 1600 meters thick, has been found in the Olympic Mountains by Arnold[2] and tentativly correlated with the Californian late Mesozoic. It is covered unconformably by the Eocene.

The Eocene system is better represented and more widely distributed than almost any other in the Coast Ranges. Generally it consists of a thick succession of clastic sediments,—sandstone and shale predominating in different places. With these, thin deposits of volcanic breccia and tuff are locally interbedded. In the north, the Eocene sediments are generally coarser and contain some coal beds. In southern California shale predominates and marine fossils are common. In the south, however, there is much local variation, and here and there such obviously terrestrial formations as red gypsiferous sandstone are found. In age these beds range apparently from lower Eocene into the Oligocene, but the latter period is unrepresented in many places. Altho there are local unconformities, in some districts no break has been found in the entire sequence from Cretaceous to Miocene.

In California the Miocene formations are thick and well exposed. Shale predominates, but there is much sandstone and chert. Near San Francisco the Monterey formation (about 1600 meters thick) consists largely of white diatomaceous shale,—apparently of marine origin. Like the Eocene, the Miocene formations are variable from place to place and, altho marine fossils are found abundantly in some localities, many of the beds are barren and may well be of terrestrial origin. North of California the Miocene is less well known, being found chiefly in little patches along the Pacific shore (Astoria beds). The sediments are clastic, but generally contain marine fossils. In the Olympic Range the Oligocene and early Miocene are very thick,—perhaps 5000 meters—and contain small coal deposits. This series is separated from the Eocene by an unconformity.

Pliocene beds, closely associated with late Miocene strata, are almost everywhere separated from the older sediments by an angular unconformity. The younger formations consist largely of conglomerate and sandstone, and they are best developt on the coastal side of the mountains.

[1] Diller, J. S., Port Orford, Ore., Folio, No. 89. Geol. Atlas of U. S., U. S. Geol. Survey, 1903.

[2] Arnold, R., Geological Reconnaissance of the Coast of the Olympic Peninsula, Washington. Bull. Geol. Soc. of Am., vol. XVII, 1906, pp. 451—468.

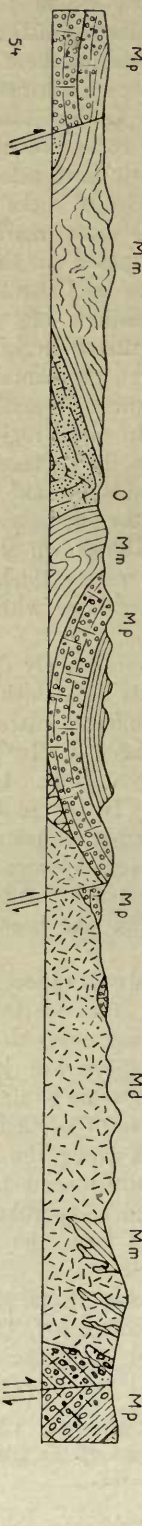


Fig. 53. Profile of a part of the Santa Cruz Mountains in the Coast Range of southern California. (After R. Arnold, U. S. Geol. Surv.) — O, Oligocene sandstone; Mm, Lower Miocene [Monterey] shale; Mp, Upper Miocene or Pliocene [Purisima] conglomerate, sandstone and shale; Md, Middle Miocene diabase.

Fig. 54. Profile of folded Tertiary sediments in western Oregon. (After J. S. Diller, U. S. Geol. Surv.) — E, Eocene sandstone and shale; Q, Quaternary sediments.

The Quaternary formations are in general much like those of the late Tertiary, — consisting of partly consolidated sand and gravel. Near the shore these contain marine fossils but on the eastern slope they are generally River-made. Altho almost no glacial deposits have been found in the Coast Ranges south of the Columbia River, the Olympic Mountains of Washington are partly covered and surrounded with moraines and glacial gravel.

Structure.

In general the structure of the Coast Ranges is very complex in the south, but less so in the north. The Jurassic and older rocks of the Coast Ranges have been repeatedly deformed, so that they now stand on edge in isoclinal folds which have in turn been broken into mere shreds by successiv large intrusions of plutonic rocks. In consequence the sediments are generally much metamorphosed. Altogether these older rocks may be regarded as a part of the same intensely crumpled mass as the Sierra Nevada.

The rocks from Comanchean to middle Miocene appear to be almost a unit structurally. It is true they are separated by minor unconformities in some districts and as already noted, angular unconformity within the series has been reported locally. The rocks have been folded along lines which are roughly parallel to the coast, altho the strike varies considerably from point to point. Thus in southern California the trends are east and west, in central California northwesterly, in Oregon nearly due north and in the Olympic Mountains again northwest. In general the Pacific shore line cuts diagonally across the axes of the folds in a more nearly north-south direction, so that, except in the Oregon mountains, the folds come out one after the other to the ocean and disappear.

The folds in southern California are generally steep, many of them comprest and some even overturned, here toward the southwest and there to the northeast. The folds are in turn cut by many faults which are in general parallel to the folds. These faults are not readily classified as either normal or reverse faults, for on most of them there has been much horizontal movement. In the Oregon mountains the folds are open anticlines and synclines with few faults. In the Olympic range also the folds are rather gentle, but locally the beds have been more comprest and faulted.

The later Tertiary rocks, chiefly Pliocene, are less disturbed than those beneath, but are rarely horizontal. In many places they dip away from the axis of the range both eastward and westward. In southern California, however, the Pliocene and late Miocene strata have been more folded and faulted, so that locally the beds stand in vertical position or lie beneath overthrusts.

The later Quaternary sediments and glacial deposits are generally horizontal, resting in markt unconformity upon the eroded edges of older beds. In southern California again, where deformation has been repeated so many times, even the Quaternary sediments have been more or less faulted and occasionally dip at angles of 10 to 15 degress.

Geologic History.

The history of the Coast Ranges element prior to Comanchean time is but little known, and, so far as the facts are understood, they indicate that it resembled that of the Sierra Nevada. The predominance of clastic sediments in the Paleozoic and early Mesozoic rocks of California suggests that a considerable body of land may have occupied a position near the present Pacific coast and hence along the site of the Coast Ranges.

During the Comanchean and Cretaceous periods, clastic sediments were being rapidly deposited in northern California and southern Oregon, and more than probably all along the west coast of the United States. The sediments seem to imply the existence of a coastal plain, partly submerged and partly above the sea. This plain was subject to the advance and retreat of an oscillating shore line.

In southwestern Oregon Diller[1] reports the Eocene beds resting on the highly folded Comanchean system, and in the Olympic range Arnold finds similar relations. It is thought that the folding came just after the deposition of the Knoxville beds. There were intrusions of serpentine at the same time. In California there seems to be less evidence of disturbance at the close of the Comanchean or Cretaceous periods of sedimentation. The same activities continued into the Tertiary with interruptions by local emergence and erosion at various times and places. In the northern part of the region the Cascade mountains were probably bordered on the west by a marshy coastal plain upon which rivers were rapidly building up a thick series of coal-bearing strata. In California on the south, this plain appears to have been more largely submerged, leaving only a narrow terrestrial strip. Climatic differences between the north and south not unlike those now prevailing are suggested by the prevalence of coal seams in Washington and the occurrence of gypsum beds in the Eocene of southern California.

Near the middle of the Tertiary period the west coast was subjected to its principal diastrophic movement. According to Arnold[2], the disturbance took place in late-middle Miocene time. The movement was one of lateral compression,—doubtless originating in the Pacific basin,—and its result was the mild folding of the early Tertiary beds in Washington and Oregon and the much more intense crumpling of those in southern California. To this disturbance is ascribed the existence of the Coast Ranges as topographic features.

Following the folding there appears to have been much local difference of conditions. Erosion must have followed the folding thruout the region; and from Washington to northern California it seems to have continued with only brief interruptions down to the present time. In central California a relativly thin deposit, partly marine and partly fluviatil, was laid down upon the eroded folds. In southern California a brief but effectiv episode of erosion was followed by the deposition of a great sheet of gravel

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[1] Diller, J. S., Port Orford, Ore., Folio (No. 89), 1903. Geol. Atlas U. S., U. S. Geol. Survey.

[2] Arnold, R., The Los Angeles Oil District, Southern California. U. S. Geol. Survey, Bull. 309, 1907, p. 155.

and sand partly in the sea and partly within the coast line. After the deposition of the Pliocene sediments in southern California, that part of the Coast Ranges suffered a further compressiv movement which severely folded even the Pliocene beds. Arnold assigns this event to a time early in the Pleistocene period in California, and late Pliocene in the Olympic range. It is not improbable that it coincided with the general uplifts and warpings of which evidence is found all over the western mountains, and which Le Conte[1] suggested should be used to mark the close of the Tertiary period. The disturbance, strong or mild according to the locality, was followed by erosion, and partial truncation of the folds, where such had been produced. Late Quaternary sands and gravels were then deposited on the edges of the Pliocene beds, or on older rocks beneath them.

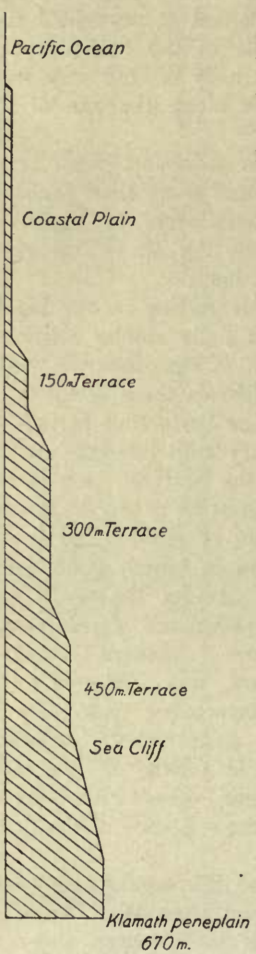

Fig. 55. Profile of marine terraces, north of Port Orford, Oregon. (After J. S. Diller, U. S. Geol. Surv.)

A change of climate comparable to that affecting all of North America in the Pleistocene period is recorded by local glaciation. In the Olympic Mountains of Washington large valley glaciers radiated from the central massif and reacht the bordering lowlands. The mountains farther south were either too low or too dry to receive much snow. However, it has recently been discovered[2] that Mt. San Gorgonio (3530 meters) in southern California supported two or three small glaciers near its summit.

Within the Pleistocene there have been important changes of level, which are best recorded by the wave-cut terraces along the Pacific Coast. These indicate successiv uplifts of the shore in some places, with sinking in others, implying differential movements. Frequent earthquakes and the phenomena of recent faulting show clearly that crustal movements are still activly going on, at least in California.

Physiography.

Topography. On account of the great variations in climate as well as in geologic structure in the course of 2000 kilometers, there is much diversity of topography in the Coast Ranges.

In the south, the mountains are rugged,—especially the higher ranges of southern California. The slopes are clad with brush and there are thin forests on the highest ridges. Between the ranges are long parallel valleys connected by transverse canyons. In general, the ridges have been carved into a maze of spurs by the growth of ramifying gulleys. Common features of the southern Coast Ranges are irregular basins partly filled with alluvium. In general the streams are small, and are perennial only in the largest valleys. There is a close correspondence between the topography and the geologic structure, for many of the ridges are definitly anticlinal, while others are tilted blocks, generally with scarps on the northeast sides. Even some of the islands of the Santa Catalina group are the tops of fault blocks, as Lawson[3] has shown in the case

[1] Le Conte, Jos., The Ozarkian and its Significance in Theoretical Geology. Jour. of Geol. VII, 1899, pp. 525—544.

[2] Fairbanks, H. W., and Carey, E. P., Glaciation in the San Bernardino Range, California. Science, new ser., vol. XXXI, 1910, pp. 32—33.

[3] Lawson, A. C., The Post-Pliocene Diastrophism of the Coast of Southern California, Univ. of Cal. Bull., Dept. Geol. Vol. 1, No. 4, pp. 115—160, 1894.

of San Clemente. Most of the larger valleys are either fault basins or downwarps. Some of them contain lakes which have been formed by the disturbance of drainage in the course of faulting. Those south of San Francisco are well known examples of this kind. In that particular locality the chief movements along the faults have been horizontal, giving rise to a peculiar discordance of topographic features without the production of great relief.

In Oregon and Washington the topography and structure correspond much less closely. The summits are generally rounded and densely covered with forest. The mountains are intersected by canyons, but the drainage pattern is much coarser on the average than in southern California. The Olympic Range has been strongly modified by local glaciers, which have left the portion above timber-line (1700 meters) bare and craggy, while the lower courses of the valleys are clogged with thick moraines. All thru the northern Coast Ranges the rivers are large and perennial, because the rainfall of the region is plentiful.

Where the ranges slope down to the Pacific Ocean on the west, the coast is abrupt and, being fully exposed, it has been eroded into ruggedness by the ocean waves. The strength of the wave currents is such that no deltas can be formed, but at the mouths of the rivers sand bars have been built. The coast is markt thruout by a series of wave-cut terraces, the highest of which is 500 meters above sea level. Many of these terraces are markt by sea caves, isolated rock stacks and thin deposits of beach gravel and shells.

Origin and History of the Topography. That the physiographic history of the region is complex is generally admitted, and the details of that history are but imperfectly known. The topography has been formed largely by two agencies, namely (a) diastrophism in the form of warping and faulting, and (b) erosion by running water. The latter has been important thruout the region and has controlled in the north. The former has dominated only in certain parts of the California Coast Ranges. Three agencies of less importance have modified the topography in detail:—(a) waves, which have left their unmistakable impression on the Pacific shore; (b) glaciation, which has done notable work only in the Olympic range, and (c) the wind, which in addition to building dunes locally along the coast has helped to sculpture in detail the rock exposures in the dry southern ranges.

Among students of the region it is generally agreed that the existing topography is not older than Miocene. As to the events of post-Miocene topographic history there is less unanimity of opinion. Arnold[1] finds well markt remnants of a peneplain surrounding the Olympic range at elevations of 1200 to 1500 meters above sea level. In the Klamath Mountains Diller[2] has found a similar dissected upland which bevels the edges of folded Cretaceous and older strata. He is inclined to regard it as Miocene, but admits that it may be later. It agrees better with the known physiographic history of western United States to refer it to the Pliocene. The old surface has been warpt and is not everywhere identifiable. Anderson[3] suggests that most of the streams crossing the Klamath Mountains are antecedent and have cut thru ridges warpt up athwart their course. In California, Lawson, Fairbanks, and others have recognized a gently undulating surface which truncates late Miocene folds. This is believed to represent a Pliocene peneplain now much dislocated by later faulting and warping. It is obvious

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[1] Arnold, R., Geological Reconnaissance of the Coast of the Olympic Peninsula, Washington, Bull. Geol. Soc. of Am., vol. XVII, 1906, pp. 451—468.

[2] Diller, J. S., Topographic Development of the Klamath Mountains. U. S. Geol. Survey, Bull. 196, 1902, p. 47.

[3] Anderson, F. M., The Physiographic Features of the Klamath Mountains. Journ. of Geol. vol. X, 1902, pp. 158—159.

that, owing to the markt post-Pliocene deformation, no earlier peneplain in the Coast Ranges retains its original continuity, altho remnants may be found in favored places.

Since the reduction of the region to such a general or perhaps several local peneplains, various changes have occurred. In the Klamath Mountains there are remnants of wide valleys, on the ancient floors of which gravel deposits still remain. In some of these gravel deposits sharks' teeth have been found, indicating that the valleys were, at least temporarily, estuaries. At that time the land must have been 300 to 500 meters lower than now, and simultaneously the prominent terrace 300 meters above sea level along the Oregon coast was doubtless cut by the waves of the Pacific. The broad upper valleys are now entrencht by deep canyons, which are wide where they are parallel to the beds of soft Tertiary rocks but narrow where they cross the upturned Paleozoic beds. Some of these younger valleys in the Klamath Mountains were occupied by small glaciers in the Pleistocene period.

In California, especially in the southern portion, the testimony of terraces and valleys together indicates great changes of level from the Pliocene to the Recent period. The finding of mammoth bones on Santa Rosa Island[1] indicates that the land once stood more than 300 meters higher than now, thus extending the shore far westward. Valleys deeply filled with gravel and sand, as well as submerged canyons along the continental shelf, seem to corroborate this view. Lawson shows that the changes in level have been differential, for while the island of San Clemente and the adjacent coast have risen some hundreds of meters, the neighboring island of Santa Catalina has remained stationary or subsided a little. There can be no doubt that this post-Pliocene movement was far more complex than mere general elevation.

To a later subsidence of the coast, probably in early Pleistocene time, is ascribed the cutting of the highest ocean terraces 300 to 500 meters above the present sea level. Probably it was at this time that the Willamette valley of Oregon was half submerged, —as shown by the clays with marine shells, which stretch as far south as Eugene. There is evidence in the marine Pleistocene deposits of Mt. Diablo that the California valley was also temporarily occupied by the sea.

The subsidence was followed later in the Pleistocene by general but differential uplift, and, judging from the series of sea benches beneath the highest, the rise must have been halting.

The tidal estuaries of the rivers along the Oregon coast and at San Francisco indicate a recent subsidence of 100 to 200 meters. Since then some of the bays have been cut off by sand bars, and lagoons have been more or less filled with wash from the land.

Seismicity.

The Pacific coastal ranges are subject to more frequent earthquakes than any other part of the United States. Not all portions of the coast are, however, equally affected. From southern Oregon north to British Columbia slight earthquake shocks are felt at rather frequent intervals, and there was one severe shake along the Columbia river in 1873. Of disastrous earthquakes there is, however, no record. The Klamath Mountains, partly in Oregon and partly in California appear to be even more stable. The Coast Ranges of California constitute, however, a very active seismic province. From Cape Mendocino south to San Francisco Bay earthquakes are of frequent occurrence and thence south into Mexico they appear to be even more so. Lists[2] of earthquakes from 1892 to 1906 show that tremors readily perceived by the senses occur several times every month; while about one shock a year is violent enough to

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[1] Fairbanks, H. W., San Luis, Cal. Folio (No. 101). Geol. Atlas U. S., U. S. Geol. Survey, 1904.

[2] Perrine, C. D., Earthquakes in California, Bulls. 112, 114, 129, 147, 155 and 161, U. S. Geol. Survey.

do some damage to human property. For any one point along the coast the destructiv earthquakes would be much less frequent. At San Francisco there have been two great catastrophes in the past century. The earthquake of 1868 partly demolisht the city, while that in 1906 did even greater damage. There seems to be general agreement

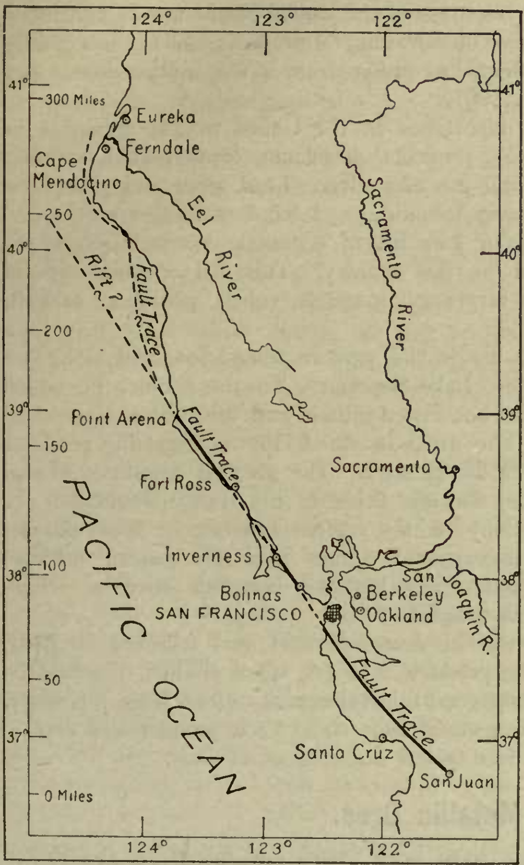

Fig. 56. Map of the vicinity of San Francisco Bay, showing the course of the fault which caused the earthquake of 1906. (After G. K. GILBERT, U. S. Geol. Surv.)

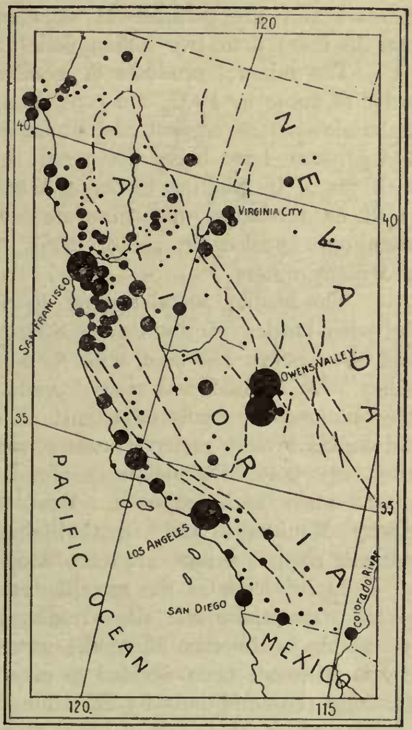

Fig. 57. Sketch map of California and vicinity, showing the distribution of important earthquake epicentra. (After MONTESSUS DE BALLORE).

that most of the Californian earthquakes have been caused by small displacements along fault planes, of which there are many in the Coast Ranges. The great earthquake of 1906 has been carefully studied by a competent commission[1], who found that the shake was caused by a nearly horizontal slip along a fault plane parallel to the Coast Range and passing thru the west edge of the city of San Francisco.

[1] GILBERT, G. K., HUMPHREY, R. L., SEWELL, J. S., and SOULÉ, FRANK., The San Francisco earthquake and fire of April 18, 1906, and their effects on structures and structural materials. U. S. Geol. Survey, Bull. 324, 1907.

V. Economic Geology.

Introduction.

It is well known that the mineral resources of the United States are of enormous value. During the last century the number of raw mineral products utilized has greatly increast and the commercial value of them has grown from a few million dollars per year to more than two billion dollars in 1907.

The mineral products of greatest importance in the United States, arranged in order of value in 1907, are coal, iron, clay products, petroleum, copper, gold, building materials such as cement and stone, natural gas and silver. Lead, zinc, rock phosphate and gypsum have been discovered in many localities, and large quantities are mined each year. In addition to these there is a long list of economic products of which small or moderate quantities are found in this country. This list includes ores of aluminum, quicksilver, nickel, gems, the rare earth minerals, cobalt, platinum, asphalt, and many others.

The leading metal mining districts are in the western mountains, and along the northern border of the United States near Lake Superior. To these must be added also the eastern highland, with its smaller but varied mines, and the central Mississippi valley with its lead and zinc deposits. The areas in which the non-metallic products are obtained are scattered almost all over the country. The greatest quantities of coal are mined in the eastern interior region, but the fields in the Rocky Mountains are also important. Petroleum is found chiefly in the eastern interior, in the southern coastal plain and California. Most of the gypsum comes from the eastern interior, Rocky Mountains and Great Plains, but other building materials such as stone, cement, clay, and lime are very widely distributed.

In this chapter the metallic ores will be described first and followed by fuels, building materials, and other non-metallic products. In the space allotted, it would be impossible to describe all of the more important mineral deposits of so large a country. It has therefore been decided to give the general facts about each product and then to illustrate the conditions by describing a few typical occurrences of each.

A. The Metallic Ores.

The ores of nearly all the metals have been found and mined in the United States. Of some, however, there are greater quantities than in most other countries, and of others only small amounts have yet been discovered here. Iron is easily the leading metal of the United States, altho gold and copper are both of great importance. Silver, lead, zinc, and even aluminum are produced in relativly large quantities.

On the other hand the United States yields much less platinum, nickel, and tin than some other countries. Of the rarer metals such as cobalt, vanadium, and tantalum, the supply is small and scattered.

Iron.

Modes of occurrence. Ores of iron are found in bodies of different forms and relationships in many parts of the United States. The largest and most important deposits are in the form of strata interbedded with other sedimentary rocks, or altered portions of such strata. The original materials are clearly of sedimentary origin, like the rocks above and below them, but the present value of the deposits is due largely to subsequent changes which have concentrated the iron minerals at the expense of the other components of the rock. The ores which occur in this form are hematite, limonite, and siderite (iron carbonate). Many of the limonite ores are residual deposits

resting upon deeply weathered limestone. The carbonate ores are often found in association with coal beds and are evidently unaltered sedimentary precipitates. Most of the older ore-bodies consist of hematite, and they appear to have been derived from chemically precipitated iron compounds which have since been altered and concentrated in the form of solid masses of hematite.

A type of deposit which is commonest in the western mountains of the United States, altho represented also in southeast Pennsylvania, includes bodies of hematite and magnetite formed at the contacts between igneous and sedimentary rocks. The intrusions are usually large and laccolithic in form, and the wall rock is generally limestone.

Iron ores of another class, of still less commercial importance, appear to be original segregations in intrusiv igneous rocks. These deposits are found here and there in the Rocky Mountains and in the Piedmont-New England region. Nearly all of them consist of magnetite, and many contain so much titanium oxide that they can not be smelted profitably by present methods.

Other bodies of ore, chiefly magnetite, are found in the form of lenses interleaved with gneiss and schist, among the highly metamorphosed rocks of the Piedmont belt and Adirondack mountains. The exact origin of these is not known. Probably they were originally like some of the other bodies above described but have been intensely metamorphosed.

Distribution.

Geographic. The greatest deposits of iron ore thus far discovered in the United States are grouped around Lake Superior in the states of Michigan, Wisconsin, and Minnesota. The ores are found in several districts or "ranges" (as they are locally called). In the order of their present importance these are the Mesabi, Marquette, Crystal Falls, Menominee, Penokee-Gogebic, Vermillion and Cuyuna districts. The Marquette, Crystal Falls, Menominee, and Gogebic ranges are in the northern peninsula of Michigan, on the south shore of Lake Superior. The Mesabi, Vermillion and Cuyuna ranges are in northern Minnesota. As exploration continues, the known area of the iron districts is being extended. At the present time this extension is moving chiefly westward and southwestward from the known ranges in Minnesota. In that region the rocks are deeply covered with glacial drift so that exploration is carried on almost entirely by means of diamond drilling.

The second most important iron region of the United States stretches from Alabama to New York, along the Appalachian Mountains. The iron ore deposits there are found scattered along the outcrop of the folded Silurian rocks, one of the formations of which is more or less ferruginous thruout the region.

In the Adirondack Mountains of New York and also in New England and the highlands of the Carolinas, deposits of magnetite are found infolded with the ancient crystalline rocks or associated with intrusivs. They yield but a small proportion of the iron now produced in the United States.

Among the western Mountains, bodies of iron ore which are either contact deposits adjacent to igneous intrusions or actual segregations from such igneous rocks, are found in Wyoming, Utah, California, Washington, and several other states. They have not yet been much utilized, but they are potentially important for the future.

In many other parts of the United States small bodies of iron ore have been found. Some of these are mined today but others have been exhausted. One of the best known of these deposits is in the St. Francis Mountains of southeastern Missouri, where a thick body of hematite much like the Lake Superior ores is found associated with pre-Cambrian rocks. In the Coal Measures of the upper Ohio valley, deposits of siderite have been important in the past and are still mined on a small scale. It was

Fig. 58. Distribution of iron ores in United States.

these so-called "black band ores", associated with coal, that gave the city of Pittsburg, in Pennsylvania, its initial importance as an iron manufacturing center.

Stratigraphic. Altho deposits of iron ore occur in rocks of nearly all ages in the United States, the more important ores come from a relativly few systems. The greatest iron deposits are those in the Algonkian rocks of the Lake Superior region. Next to these come the Silurian ores of the Appalachian Mountains, together with a little in central Wisconsin. The carbonate ores of Pennsylvania, Ohio, and West Virginia, which were formerly much more important than now, are of Pennsylvanian (upper Carboniferous) age. The contact deposits are of various ages. In the West they are associated chiefly with Tertiary eruptivs intruded into Paleozoic limestones. The limonite ores and bog ores are largely younger, —either Tertiary or Quaternary.

Typical Iron Ore Districts.

The Mesabi District. The Mesabi district, in Minnesota, northwest of Lake Superior, contains at this time the most productiv iron mines in the world. The ores here are hematite and, being soft and almost unconsolidated, they can be workt very easily. As described by Leith[1], the older rocks of the district are highly folded Archean schists, overlain by lower Huronian quartzites and slates, into which granite has been intruded. Upon the edges of these highly inclined beds, upper Huronian (late Algonkian) formations rest unconformably. This system consists of a thin basal quartzite followed by ferruginous chert and iron ore, which are in turn covered by a great thickness of shale or slate. The upper Huronian rocks are but gently inclined in the Mesabi district, altho in other parts of Minnesota they are more highly folded. On the eastern edge of the district, where the upper Huronian beds have been intruded by granite and gabbro, the sedimentary formations are considerably metamorphosed, and the iron ores are of little value.

The Mesabi ore bodies are very broad at the surface, but are not deep and probably do not extend far along the dip of the strata. The ferruginous portion of the upper Huronian beds consists partly of small green nodules of greenalite. The minute grains, which bear considerable resemblance to those of oolitic formations, are imbedded in silica; and there are alternating bands, some of which are richer in the greenalite granules while others consist largely of chert. The ore bodies are believed to be merely weathered portions of this banded iron formation. During the progress of alteration the silica was removed in solution by circulating underground water; and at the same time some hematite was introduced, thus increasing the richness of the ore. This explanation accounts not only for the purity of the ore, much of which contains

[1] Leith, C. K., The Mesabi Iron-bearing District of Minnesota, U. S. Geol. Survey, Mon. XLIII, 1903.

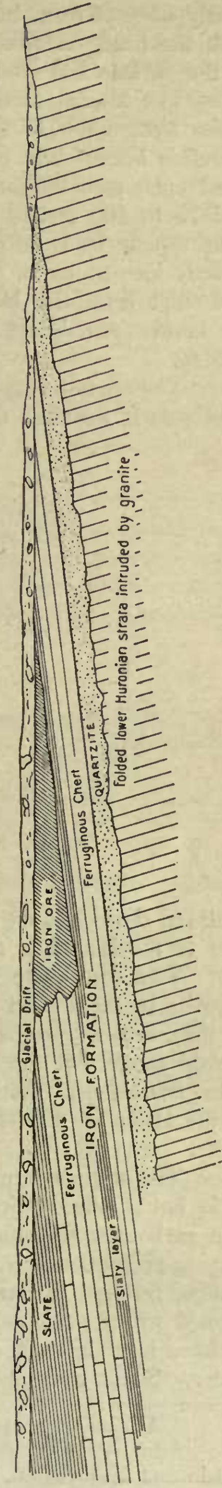

Fig. 59. Profile in the Mesabi district, Minn. showing the iron-bearing upper Huronian rocks upon folded lower Huronian and older formations. (W. J. Mead.)

nearly 64% of iron, but also for the porous crumbling character of the ore as contrasted with the hard "taconite".[1] It also explains the fact that the ore deposits are richest at the surface and do not retain their purity down the dip.

The Mesabi strata are generally buried under a mantle of glacial drift which varies from a few to 20 or more meters in depth. Most of the ore deposits have therefore been found by making borings or test-pits thru the drift. The mines are great open pits, the largest of which are now more than $1^1/_2$ kilometers in diameter and 75 to 100 meters deep. The ore itself is so soft that the work of excavating is done rapidly by large steam shovels, which run on railroad tracks and load the ore directly into trains of full-size cars. Vast quantities of high grade ore have been mined and shipt from the Mesabi region since its discovery in 1891. It is estimated that the known remaining portion will last only a few decades at the present rate of mining.

The ore is transported by rail to Lake Superior, and thence in specially constructed steel vessels thru the Great Lakes to the smelters in Ohio, Pennsylvania, and along the

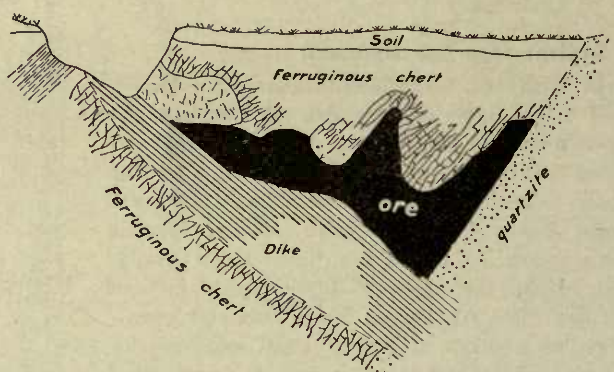

Fig. 60. Profile of an iron ore deposit in the Penokee district, northern Michigan. (After C. R. Van Hise.)

southern shore of Lake Michigan. It has been found more profitable thus to transport the iron to the coal than the coal to the iron.

The Penokee District. The Mesabi district is almost unique among iron deposits in the United States. The commoner type is illustrated by the Penokee range[2] of the northern peninsula of Michigan. There the ore is of the same age as in the Mesabi range, but the upper Huronian rocks have been highly folded along with the older formations. For this reason the iron formation outcrops in a narrow band parallel to the strike of the folds and the ore bodies dip steeply northward beneath younger rocks.

The original formation appears to have been in this case not a siliceous greenalite rock, but a siliceous iron carbonate rock, for which no specific name is in use. The iron carbonate is found interbedded with cherty and jaspery layers which contain a varying proportion of iron. Thru the alteration of these rocks by circulating underground waters, believed to have come chiefly from above, rich deposits of iron ore have been formed where the conditions were favorable. One of the necessary antecedents seems to have been in each case a trough-like structure, to direct the flow of the dissolving water. Such troughs have been formed in many places by basic dikes, originally

[1] A local term applied to the cherty iron-bearing rock.

[2] Irving, R. D., and Van Hise, C. R., The Penokee Iron-bearing Series of Northern Wisconsin and Michigan, U. S. Geol. Survey, Mon. XIX, 1892.

intruded in nearly vertical position, but since folded over into an inclined attitude. Thru the removal of silica, the alteration of the siderite to hematite, and the further filling of the pore spaces by more hematite from solution, small parts of the iron formation have been converted into solid masses of hematite. This phase of the hematite is known locally as "hard ore" in contrast to the "soft ore" of the Mesabi and some other districts.

In the Penokee and similar ranges most of the mining has been done from shafts, of which some have reacht a depth of more than 500 meters. It is usual to dig the shafts beneath the ore and then run tunnels from it to the inclined ore body at various levels.

Altho the Penokee district is here taken as an example of those in which relativly hard ores are found in highly folded strata and are mined from shafts, there are other districts of equal or greater importance which have similar characteristics. These are the Marquette[1], Crystal Falls[2] and Menominee[3] districts of Michigan, the Florence and Baraboo districts of Wisconsin, and the Cuyuna[4] and Vermilion[5] ranges of Minnesota. They differ from each other in details of the geologic succession and structure but all belong to the same general class.

The Birmingham District. This is situated in Alabama near the southwest end of the Appalachian Mountains, in which the rocks are folded Paleozoic sedimentary formations. Southwestward the folds are concealed by Cretaceous and younger beds. The iron ores are deposits of soft red hematite interbedded with shales and sandstones of Silurian age. Individual ore beds are generally 1 to 4 meters thick, altho some

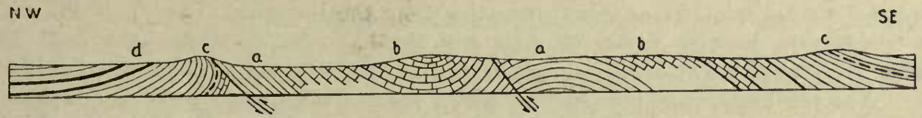

Fig. 61. Profile near Birmingham, Ala.: a, Cambrian slate; b, Ordovician limestone; c, Silurian formation containing iron ore; d, coal seams in Carboniferous shale. (After C. Butts, U. S. Geol. Surv.)

reach a thickness of 10 meters. Some of them are nearly pure hematite. Others consist of pebbles and sand cemented by hematite. Still other beds have the structure of fossiliferous limestone and oolite, altho materially ferruginous. The beds continue to show about the same character when followed down the dip, except that the percentage of lime carbonate is higher below the weathered zone. This and other facts indicate that the ore was originally a sedimentary deposit, and that it has not been notably altered since it was formed, except that lime carbonate has been leacht out near the outcrops. That it was deposited in the sea is implied by the presence of abundant fossils in some parts of the ore. Eckel and Burchard[6] suggest that the beds were deposited in shallow bays parallel to the shore.

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[1] Van Hise, C. R., and Bayley, W. S., The Marquette Iron-bearing District of Michigan, U. S. Geol. Survey, Mon. XXVIII, 1895.

[2] Clements, J. M., and Smyth, H. L., The Crystal Falls Iron-bearing District of Michigan. U. S. Geol. Survey, Mon. XXXVI, 1899.

[3] Bayley, W. S., The Menominee Iron-bearing District of Michigan, U. S. Geol. Survey, Mon. XLVI, 1904.

[4] Van Hise, C. R. and Leith, C. K., Geology of the Lake Superior Region, U. S. Geol. Survey, Mon. LII, 1911.

[5] Clements, J. M., The Vermilion Iron-bearing District of Minnesota, U. S. Geol. Survey, Mon. XLV, 1903.

[6] Burchard, E. F., and Butts, Charles., Iron Ores, Fuels, and Fluxes of the Birmingham district, Alabama. U. S. Geol. Survey, Bull. 400, 1910.

The Birmingham ores contain a remarkably low percentage of iron, the average being 30 to 40 percent. The impurities consist of both silica and calcite in varying proportions,—the latter predominating. In some beds there is enough calcite to remove the silica in the process of smelting. The utilization of such low grade ores is made possible in this district partly by the favorable composition of the ore and partly by the fact that both coal and limestone required in the smelting of the ore are obtainable in the same district. The ore is smelted near the mines and reduced to both iron and steel. The Birmingham district alone, exclusiv of other portions of Alabama, produced about 3000000 metric tons of ore in 1907. It thus ranks second to the Lake Superior district, altho its production is still very much less than that of the latter.

Deposits similar in general character to those near Birmingham are found at many points thru Tennessee, Virginia and Pennsylvania to New York along the Appalachian folds, and even in east central Wisconsin. The ores are remarkably similar thruout this wide range of territory and they have been utilized for more than a century.

Iron Springs, Utah, District. The iron ores of southwestern Utah may be taken as typical of the deposits found at the contacts of igneous intrusions. Near Iron Springs[1] an andesitic magma has penetrated a thick Carboniferous limestone and formed laccoliths. Along the contact between the andesite and limestone irregular bodies of iron ore have been found, and there are others of smaller size in cracks in the andesite. The ore seems to be an intimate mixture of magnetite and hematite, the former predominating. The ore bodies are evidently replacements of the limestone and have been formed under the direct influence of the intrusions. It is believed that they were deposited by hot solutions or gases emanating from the intrusion. The ore bodies show no tendency to decrease in size or value with depth, so far as shafts have been dug, and if the interpretation of their origin is correct they can not well be superficial.

The ore averages 56 percent iron with 7 percent silica and 2 percent phosphorus. At the surface the iron oxide has been somewhat concentrated so that locally the deposits contain as much as 69 percent of metallic iron. The surface concentration is evidently due to relativly recent weathering. Thus far these particular deposits have not been much mined, for the owners have only recently past beyond the exploration stage in their operations.

Other contact deposits of similar origin have been found in several other parts of western United States.

Mineville, New York. The Mineville deposits on the east side of the Adirondack Mountains of New York are typical of the magnetite occurrences of eastern United States. The ore bodies are lenticular in form and interleaved with gneisses and limestones. All the beds are intensely folded and the ore bodies are not only twisted, but some are abruptly cut off by faults. The rocks are of pre-Cambrian, probably Algonkian age, and altho now highly metamorphic it is generally believed that they were originally sedimentary. They are associated, however, with various kinds of igneous intrusions.

The ores vary considerably in composition. Some contain rather large proportions of phosphorus, sulphur, and titanium; but others are nearly pure and yield a good Bessemer grade of ore. Bodies of pure ore are generally not large, the greatest being about 100 meters thick and 1/2 kilometer in length. Poorer ores, containing a large proportion of silica exist, however, in much greater quantities. The titaniferous bodies are not utilized at present, but their volume is relativly great and they may be valuable in the future.

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[1] Leith, C. K, and Harder, E. C., The Iron Ores of the Iron Springs district, southern Utah. U. S. Geol. Survey, Bull. 338, 1908.

From the Mineville district an average of about 450000 metric tons of ore is shipt each year, but in recent years some of the deposits have been exhausted and not many new discoveries are being made.

Other deposits of magnetite, either associated with gneisses[1] and schists or with intrusions of Triassic diabase[2], are found all around the borders of the Adirondack Mountains, in the highlands of New Jersey and southeastern Pennsylvania, and among the pre-Cambrian rocks of North Carolina and Virginia. At Asheville in North Carolina one of the largest known bodies of high grade Bessemer magnetite is being mined.

The Pittsburg District. The parts of Ohio, West Virginia and Pennsylvania centering in the city of Pittsburg were formerly important as an iron producing district. The use of local ores has now been largely abandoned because vast quantities of better ore are obtained cheaply from the Lake Superior region. The western Pennsylvania iron ores are found in the upper Carboniferous rocks, generally beneath coal seams. They occur in the form of layers a meter thick or less, and also as nodules imbedded in clay. Both the continuous layers and the nodules consist of iron carbonate with more or less clay and other impurities. In some of the layers bituminous matter is sufficiently abundant to give the ore a black color,—whence the name "black band ores", by which they have long been called.

Altho these ores are of comparativly low grade and not easily obtained in great quantities they are still a source of iron because they can be smelted at low expense. In the same formation which contains the ore there is also coal of the best quality and suitable limestone, so that all of the materials necessary for smelting the ore may be obtained in the same locality.

The production of these carbonate ores has declined and is now of small importance. They are of interest chiefly as examples of a particular type of iron ore deposits.

Russellville District. This is selected as an example of many localities in which younger hydrated iron ores are mined. At Russellville, in north central Alabama, the more important ore bodies lie in hollows on the irregular weathered surface of Carboniferous limestone, while others, evidently derivativ, are interbedded with layers of Pliocene gravel. The deposits resting on the limestone are thought to be the older,—Mesozoic or early Tertiary.[3]

The ore is generally called "limonite", but in this particular district it appears to be chiefly goethite. It occurs in the form of nodules and boulders imbedded in residual clays. It also forms a cement in conglomerate, and there are even a few beds, a meter or two thick, which consist of nearly pure ore. Selected pieces of ore contain about 59 percent of metallic iron, but in large quantities the commercial product yields only 45 to 51 percent of iron. Besides iron oxide the ore includes 12 to 20 percent of silica and clay. The ore contains very little phosphorus and sulphur, and therefore may be smelted by the Bessemer process.

The ore bodies are horizontal and sheet-like, but vary in thickness from place to place. They are mined from open pits. In 1895 the district produced 255000 metric tons of ore and the output has increast continually since then. It is believed that other deposits of the same general character will be found in the vicinity, when the region is carefully explored.

Other limonitic ores of somewhat similar nature have been found associated with Tertiary rocks upon low table-lands in eastern Texas and again in central Tennessee,

[1] Spencer, A. C., and others, Franklin Furnace, N. J., folio (No. 161). Geol. Atlas U. S., U. S. Geol. Survey, 1908.

[2] Spencer, A. C., Magnetite Deposits of the Cornwall Type in Pennsylvania, U. S. Geol. Survey, Bull. 359, 1908.

[3] Eckel, E. C., and others, Iron Ores, Fuels and Fluxes of the Birmingham district. Alabama. U. S. Geol. Survey, Bull. 400, 1910.

Missouri[1] and Arkansas. There are similar beds in California and some of the other western states.

Copper.

Modes of occurrence. The more important copper deposits of the United States vary considerably as to form and origin. Many of the largest and richest ore bodies are irregular masses of sulphides replacing limestone and generally merging into it on all sides. Altho such bodies may be decidedly irregular in shape, the majority are lenticular in rough outline and many of them lie parallel to the bedding of the limestone. Among the best known copper deposits of this type are those in southern Arizona.

Other large deposits, of which those at Butte, Montana, serve as an example, are veins in which the ore occupies more or less well defined fractures and faults.

Copper ores bedded in shales, as in the Zechstein of Germany, are known in Idaho, Texas and elsewhere, but they appear to have little value and are not workt at present. Great quantities of copper are, however, mined from coarser fragmental deposits in which the copper acts as a cement. These cementing ores fall readily into two groups. Among the first may be mentioned shatter zones in hard rocks, in which the spaces have subsequently been sealed with copper ores. Such ore bodies are very irregular in shape and distribution. The Triassic copper deposits of New Jersey are of this type. The second group is typified by the rich copper lodes of the Keweenaw peninsula of northern Michigan. There nativ copper is more or less uniformly distributed as cementing material in certain beds of conglomerate, and along the scoriaceous surfaces of basic lava flows.

Distribution.

Geographic. Nearly all of the copper now mined in the United States comes from the western mountain and plateau region and the south shore of Lake Superior. A small proportion is produced in the Piedmont belt of the Atlantic slope.

Arizona and Montana are the two great copper states of the West. In the former there are several large producing districts, each with a number of important mines. In Montana there is only one noteworthy district (Butte), but that has proven extraordinarily rich. At widely scattered points thruout the western mountain states there are other copper mines, a few of them individually important. Those of California, Utah, Colorado, and New Mexico are among the most prominent.

In the Lake Superior region there is also but a single copper district, that of Keweenaw Point, but there are many mines,—some of them large.

In Tennessee, New Jersey, Pennsylvania, and several other eastern states, small deposits of copper ores have been mined from time to time, but they are of little importance relativly.

Stratigraphic. In the United States copper ores are found in rocks of nearly all ages. The Lake Superior ores are confined to the ancient lava flows and interbedded conglomerates of late Algonkian age. In the Arizona district the ore bodies developt generally in limestone, and there the prevalent limestones happen to be of Carboniferous age. Probably a large part of the copper deposits of the West are directly or indirectly associated with late Jurassic and Tertiary intrusiv rocks, but the ore bodies themselves are generally found in country rock which may be of any age.

Typical Copper Ore Districts.

The Bisbee, Arizona, District. The Bisbee district[2], in southeastern Arizona, has yielded an enormous quantity of copper ore in recent years. The more important

[1] Nason, F. L., Iron Ores of Missouri. Missouri Geol. Survey, vol. II, 1892.

[2] Ransome, F. L., Geology and Ore Deposits of the Bisbee Quadrangle. U. S. Geol. Survey, Prof. Paper 21, 1904.

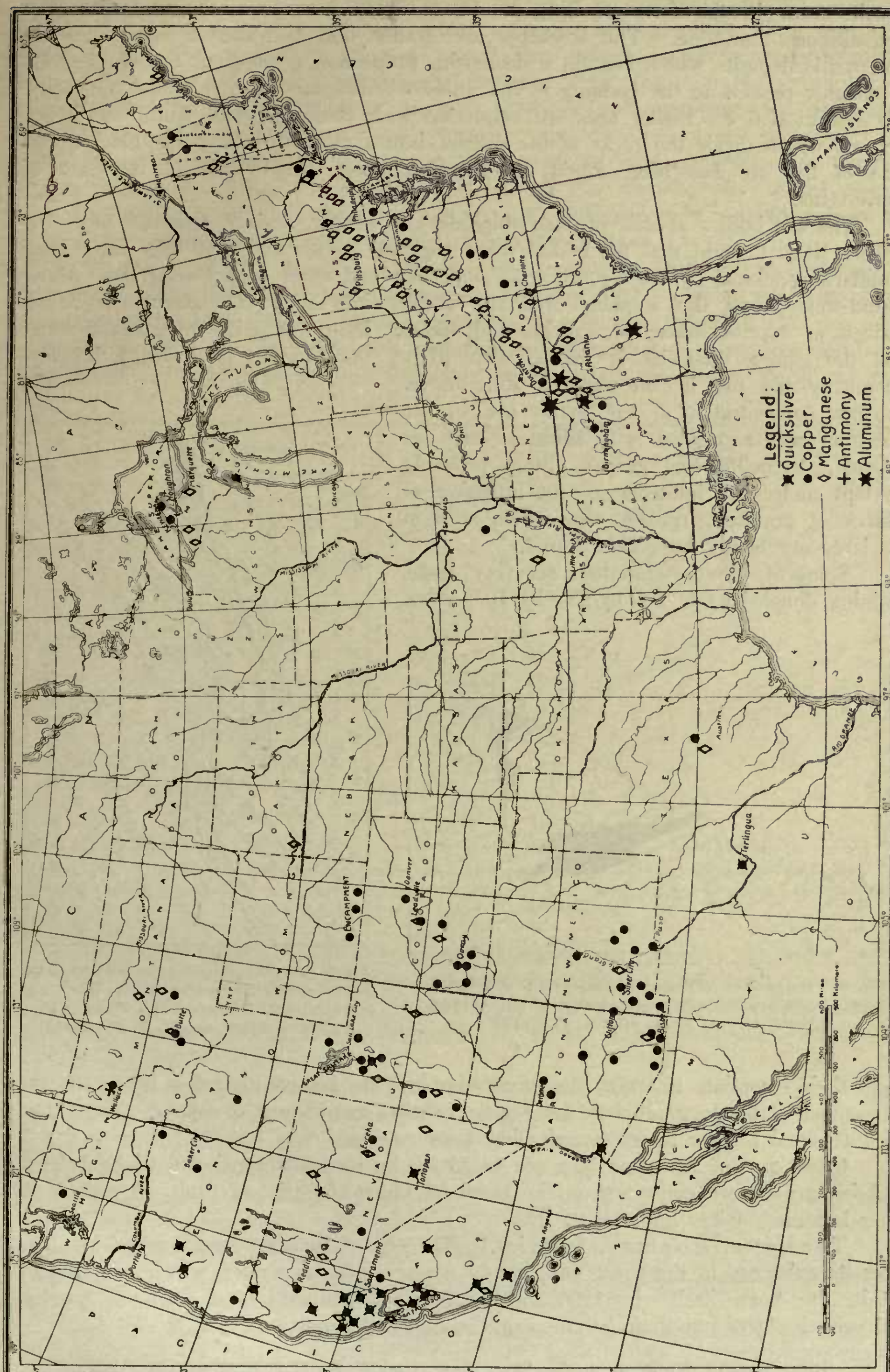

Fig. 62. Distribution of mines of copper and some lesser metals.

deposits occur in the form of irregular but roughly lens-shaped bodies within the Carboniferous limestone. The workable ore grades into the surrounding limestone thru pyritic deposits which contain a decreasing proportion of copper. The ore deposits are roughly parallel to the bedding of the limestone, but they do not follow it exactly. It is evident that the Bisbee ores are connected with the numerous faults and other fractures which divide the rocks of the district into a mosaic of irregular blocks, and some of the ore has been found concentrated along these cracks in the form of fissure-veins.

The ore bodies consist of rich sulphides of copper, locally oxidized near the surface. It is thought that the bodies were originally pyritic and that they have been secondarily enriched by the deposition of chalcocite and other copper sulphides. Above ground-water level the sulphide ores are altered into such characteristic oxidation products as cuprite, malachite, azurite, and others. In the sulphide zone below water level the gangue material is calcite with pyrite, but limonite and kaolinitic clays accompany the ore in the oxidized zone above. The first concentration of the pyritic ore in the limestone was associated with silicates, such as diopside, tremolite and garnet; these probably developt under the influence of the intrusion of a stock of granite porphyry, near which most of the large ore bodies have been found.

Some of the ore chambers are very large, attaining dimensions of 200 by 250 by 40 meters.

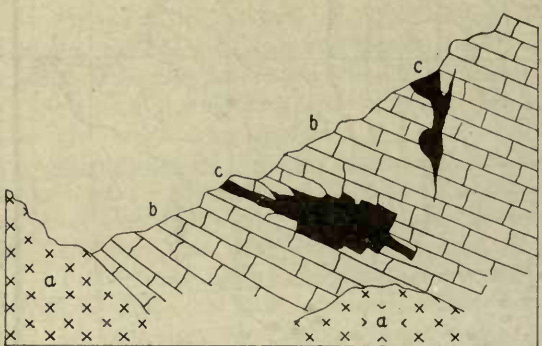

Fig. 63. Copper ore bodies at Bisbee, Ariz.: a, eruptiv rocks; b, Paleozoic limestone; c, bodies of rich copper sulphide. (From KEMP, after A. F. WENDT.)

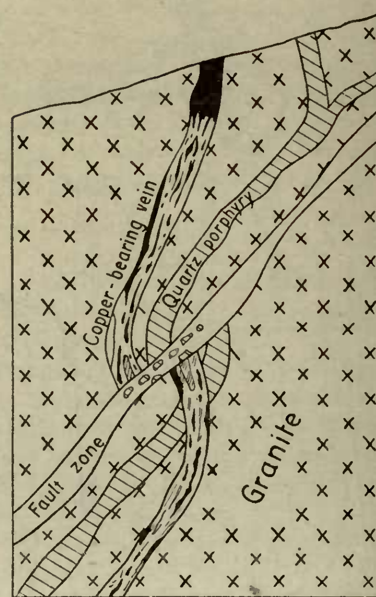

Fig. 64. Diagram showing the relation of the copper-bearing veins to faults, dikes and country rock at Butte, Mont. Black patches represent copper ore (H. V. WINCHELL).

From their inception to 1902 the production of the comparativly few mines in the Bisbee district had amounted to more than 180000 metric tons of copper. Since then an unreported but far larger quantity has been extracted.

Other ores of the same type are found in the Clifton-Morenci and Globe districts of Arizona and to some extent in the Bingham Canyon district of Utah, as well as in other localities of less importance.

The Butte, Montana, District.[1] The city of Butte in southwestern Montana owes its existence to the great copper and silver mines, many of which are situated within the town itself. In 1896 the Butte mines produced more than one quarter, and even in 1909 one-sixth, of the world's supply of copper.

[1] Butte Special, Mont., folio (No. 38). Geol. Atlas U. S., U. S. Geol. Survey, 1904.

The country rock in the vicinity of the mines is a monzonitic granite, probably of late Cretaceous age. This in turn is cut by aplite and porphyry dikes, and by a stock of andesite intruded in Miocene time. The andesite stock is accompanied by andesitic breccias and dikes and fragmental deposits of rhyolite. The Miocene eruptions appear to have produced a volcano, the neck of which, still surviving as a butte, gave the city its name.

When first discovered, the veins at Butte were mined for the free gold found in the oxidized zone. Silver, which occurs chiefly on the western side of the district, then became important, but today the copper, altho found in only a small part of the district, far outranks all the other mineral products combined.

The ores of the district consist of copper sulphides with silver and gold as accessories. The more important minerals are chalcocite and enargite, with subordinate quantities of bornite, covelite, galena, sphalerite and other minerals. The gangue is generally quartz. The ore bodies are found in a complex system of fissures and faults. The oldest and on the whole most important veins transect the granite in an east-west

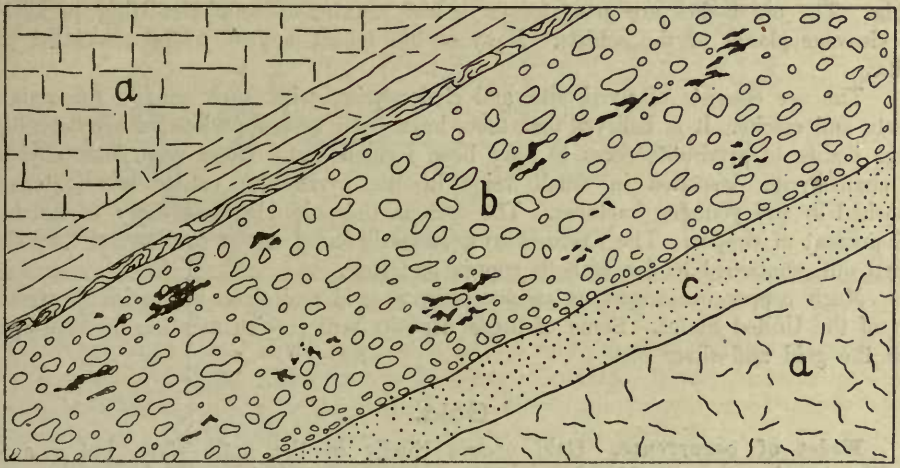

Fig. 65. Diagram showing the occurrence of nativ copper in beds of conglomerate on Keweenaw Peninsula, Lake Superior: a, diabase flow; b, conglomerate with nativ copper, irregularly disseminated; c, sandstone. (After T. A. Rickard).

direction. These veins are relativly constant in width and richness. They are broken by faults, the majority of which run northwest-southeast, altho some others trend northeast. In these faults and the crushed zones adjacent to them, there are local but very rich bodies of chalcocite, lenticular in form, and occasionally more than 30 meters thick.

The original ores are believed to have been lean cupriferous pyrite and enargite deposits left in the walls of fissures by hot magmatic solutions. These were later enriched with chalcocite and bornite,—probably by descending waters.

The Keweenaw, Michigan, District. In Keweenaw peninsula, on the south shore of Lake Superior, a great thickness of late Algonkian lava flows is found interbedded with conglomerates and coarse sandstones. Most of the flows are basic in composition, but a few are acidic. The entire series is tilted northwestward at a high angle and is bounded on the east by horizontal sandstones of Cambrian or late Algonkian age which have been faulted down against the lava flows.

In this district nativ copper fills the cavities in the scoriaceous surfaces of the lava flows and the interstices of the conglomerate beds. It is associated with smaller

quantities of nativ silver, chrysocolla, prehnite, datolite, calcite, and zeolites. It is evident that the copper and other minerals have been introduced into these porous strata by circulating underground waters; but it is not definitly known whether the mineralization was directly associated with the great basaltic eruptions of the late Algonkian or whether it occurred later. The basic flows contain small quantities of copper and it was supposed by PUMPELLY that the ores are concentrations from that source.

The ore bodies are strata of considerable thickness and they seem to persist in depth. They are mined chiefly by deep shafts, one of which is now nearly 2000 meters long, down the dip. The Keweenaw mines are by far the greatest producers of nativ copper in the United States, and, until eclipsed by Butte (Montana) in 1887, they constituted the leading copper district of the country. The production in 1909 still showed a slight increase and amounted to over 103000 metric tons.

The Ducktown, Tennessee, District. Ducktown is in the extreme southeast corner of Tennessee, in the ancient crystalline rocks on the east edge of the Appalachian Mountains. The country rocks are schists and gneisses thought to be largely of sedimentary origin. The ore bodies are great lenses of lean cupriferous sulphides lying parallel to the cleavage planes of the schists. Many of the lenses appear to be associated with faults.

The ore consists of pyrrhotite and chalcopyrite, with such gangue minerals as quartz and calcite. It is believed that there have been several periods of ore deposition. Large bodies of pyrrhotite seem to have been formed first. These were later enriched by chalcopyrite deposited in small veins in the pyrrhotite; calcite was extensivly deposited in still younger fractures. The ores in the sulphide zone carry as much as $3^1/_2$ percent of copper. The oxidized ores, formerly found at the surface but long since mined out, contained oxides of both copper and iron.

Much copper ore occurs as an accessory in gold and silver mines in the western part of the United States. Some of these deposits will receive mention in connection with the gold and silver ores.

Gold.

Modes of occurrence. Gold occurs chiefly in the nativ state, but in a few localities largely as a telluride. Most of the gold now mined in the United States comes from fissure veins, in which the gangue is generally quartz. Some important deposits take the form of irregular masses adjacent to the contacts between igneous intrusions and sedimentary rocks, but gold seems to be less common in this form than either silver or copper. Great quantities of the metal have been taken in the past from placer (alluvial) deposits and these are still important, altho declining, sources of gold. The placers may be divided into the ancient and the modern. Among the ancient placer deposits are the gold ores found in the Cambrian sandstone in the vicinity of Deadwood, South Dakota, and the much richer Tertiary gold-bearing gravels in the lava-cappt ridges of central California. Modern placer deposits in mountain valleys and to some extent along ocean beaches are widely distributed in the western mountains and plateaus, but only here and there are they profitably workt. Colorado and California are now the most important states in the production of placer gold.

Large quantities of gold are recovered incidentally from other ores, chiefly those of copper. In such districts as Butte, Montana, this accessory gold adds notably to the value of the ore.

Distribution.

Geographic. Nearly all of the gold now produced in the United States comes from the western mountain region, particularly from the states of Colorado, California,

and Nevada. Before the discovery of the western gold mines in 1848, the chief source of supply was the small group of mines in the low mountains of the southeastern states. These are still workt on a small scale but their production is insignificant as compared with that of the West.

Fig. 66. Distribution of gold mines in the United States in 1908. (Modified after F. L. Ransome.)

Stratigraphic. There appears to be no more general relation between gold ores and the age of the rocks than in the case of copper. In the Appalachian district the ores are found entirely in the ancient crystalline rocks thought to be largely of pre-Cambrian age. In the West, however, the ores may be found in rocks of almost any age. The vein deposits are, nevertheless, generally associated with intrusiv igneous rocks. These are chiefly of late Jurassic age in California, and of post-Cretaceous or Miocene age in the Rocky Mountains and plateau regions. The placer deposits are of course most abundant in Tertiary and Quaternary alluvial formations since most older deposits of this character have been either worn away or buried by younger strata.

Typical gold ore districts.

The Goldfield, Nevada, District. Among the newest and most productiv gold ore districts in the United States are those of Goldfield[1], Tonopah[2], Bullfrog, and Rhyolite, in the desert region of southwestern Nevada. Altho differing in detail the deposits in these four localities are similar in their general characteristics. The prevalent country rock consists of Paleozoic sedimentary beds, somewhat metamorphosed by granitic intrusions, probably of post-Jurassic age. These are in turn traverst by Tertiary intrusions of acid porphyrite and more or less concealed under fragmental volcanic debris and accumulations of desert alluvium. All the formations are broken by many intersecting faults.

[1] Ransome, F. L., Geology and Ore Deposits of Goldfield, Nevada. U. S. Geol. Survey, Prof. Paper 66, 1909.

[2] Spurr, J. E., Geology of the Tonopah Mining District, Nevada. U. S. Geol. Survey, Prof. Paper 42, 1905.

The ores are complex sulphides of iron, copper, bismuth, and other metals, including large quantities of gold and in some cases more or less silver. The gold is the most valuable constituent of the ore, but copper and silver are recovered in paying quantities. The ores are imbedded in flinty masses of quartz, filling relativly small, but very irregular cavities and fissures. Some of the lodes are complex fracture zones, the walls and broken fragments of which have been more or less replaced by ore.

Up to 1908 the miners dealt largely with the rich oxidized portion of the veins, containing free gold. The average value of this ore ranges from 50 to 1000 dollars per metric ton, and the maximum values in carload lots reach 7500 dollars per metric ton. Where the sulphide zone has been penetrated it is found that the value of the deposits is fairly maintained and copper there becomes more important.

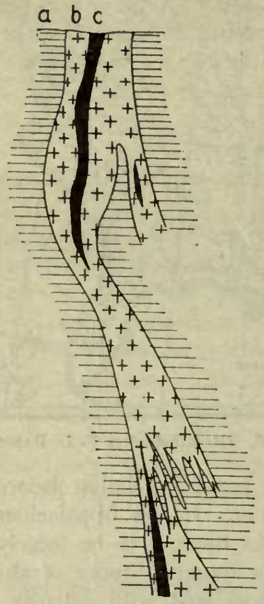

Fig. 67. Vertical section of a gold bearing vein at Goldfield, Nev.: a, country rock; b, porphyry dike; c, ore. (After F. L. Ransome, U. S. Geol. Surv.)

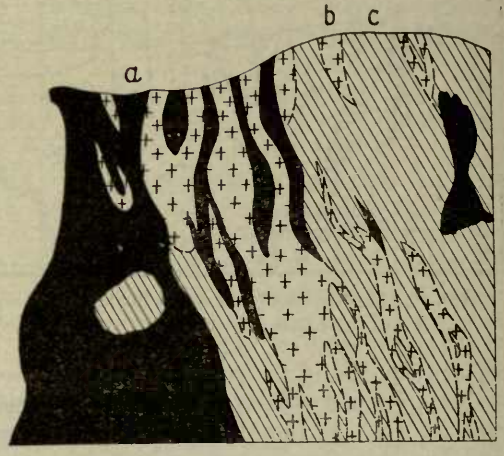

Fig. 68. Section through part of the Homestake mine in the Black Hills, South Dakota. Ore-bearing rock (a) is associated with slate (c) intruded by porphyry (b). (After J. D. Irving.)

The Homestake Mine, South Dakota.[1] The Homestake mine in the northern part of the Black Hills uplift of South Dakota is typical of gold mines in which an ore of very low grade exists in such large quantities that it can be profitably mined. The country rock of the district is schist which appears to have been derived from slates, quartzites, and basic dikes. Many of the schists are distinctly graphitic. The ore is free gold, associated usually with pyrite and quartz, and often with calcite and a little silver. None of the accessory minerals, however, seem to be essential, for the gold is sometimes found almost alone. The term "ore bodies" can hardly be applied fittingly to the Homestake deposits. The ore is merely a more or less fractured portion of the prevailing schists impregnated with gold and generally with some other minerals. The portions of this rock which can be profitably mined are very irregular in form and their limits ill defined. Rarely can the eye distinguish the ore from that portion of the rock which contains little or no gold.

[1] Irving, J. D., Emmons, S. F., and Jaggar, T. A., Economic Resources of the northern Black Hills, U. S. Geol. Survey, Prof. Paper 26, 1904.

The ore is evidently of pre-Cambrian age, since placer deposits derived from it are found at the base of the horizontal Cambrian rocks which overlie the schists. The ore seems to have no particular relation to the intrusivs in the Algonkian rocks, altho some local ore bodies are definitly associated with the Eocene intrusions of porphyry. There seems to be very little evidence of secondary enrichment of the ore, either thru concentration of sulphides or by weathering at the surface. The average value of the ore is 3—5 dollars per ton and there seems to be no variation with depth. Ore deposits of this type are rare in the United States; but in southern Alaska the Treadwell mines are similar in some respects.

Altho the ore is of exceptionally low grade the Homestake mines have been highly profitable. Up to 1900 this group of mines had yielded gold to the value of nearly 60000000 dollars and the production now (1909) generally exceeds 3000000 dollars a year.

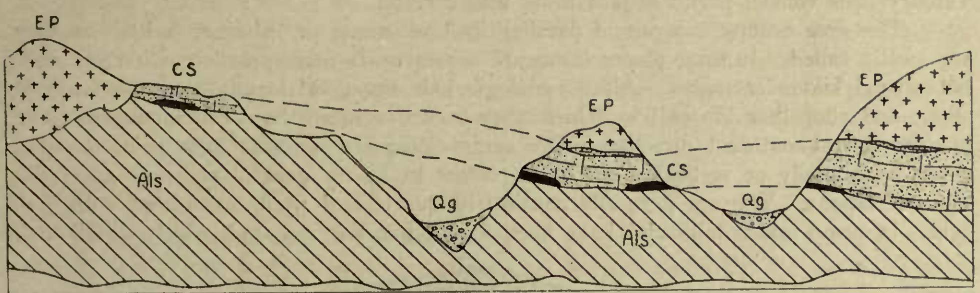

Fig. 69. Diagrammatic profile showing Cambrian and Quaternary gold placer deposits. — Als, Algonkian slates; Cs, Cambrian sandstone; Ep, Eocene porphyry; Qg, Quaternary gravel and sand. (Modified after W. B. Devereaux.)

The Cripple Creek, Colorado, District.[1] In 1908 and for several years previous the mines at Cripple Creek, Colorado, have produced considerably more gold than any other district in the United States. The prevailing rock is pre-Cambrian granite including small bodies of schist and gneiss. These ancient rocks are traverst by an intrusiv stock and dikes of phonolite. In the top of this stock a mass of phonolitic breccia occupies a funnel-like hollow supposed to be the throat of the old volcano.

The ores are found chiefly in the breccia and to some extent in the adjacent granite. They consist of the tellurides of gold,—calaverite and sylvanite,—associated with small quantities of pyrite, stibnite, galena, tetrahedrite and other metallic sulphides. The non-metallic gangue minerals are chiefly quartz, with fluorite, dolomite, adularia, and others. The ores are found in fissures the average width of which is only 1 or 2 millimeters. Rarely the veins are as much as 10 centimeters thick. In some of the mines these minute fissure veins are groupt in parallel arrangement in the form of sheeted zones of veins. The ore and gangue minerals sometimes fill the fissures completely and are even found replacing the walls in small measure. Some of the fissures are still open and are lined with drusy crystals of quartz and scattered tellurides. Lindgren and Ransome conclude that these unusual ores were deposited by tolerably hot alkaline solutions derived from the phonolitic magma, just after the intrusion of the stock and the formation of the breccia.

When the district was first discovered rich ores containing free gold were taken from the upper oxidized portions of the veins. In later years, however, the unaltered

[1] Lindgren, W., and Ransome, F. L., The Geology and Gold Deposits of the Cripple Creek District, Colorado. U. S. Geol. Survey, Prof. Paper 54, 1906.

portions of the veins, where the gold is combined with tellurium, have furnisht most of the ore. The ore is worth from 5 to several thousands of dollars per ton, the average being perhaps 50 to 100 dollars per ton. The present production of the district is worth about 12 000 000 dollars per year, and the total up to the end of 1905 was more than twelve times that amount.

The Mother Lode District, California. This district lies on the western slope of the Sierra Nevada, east of San Francisco. The prevailing rocks are of Carboniferous and early Mesozoic age. They are highly folded and considerably metamorphosed, being found now as slates, with occasional beds of quartzite and limestone and interbedded layers of andesitic and diabasic volcanic rocks. About the time of their deformation at the close of the Jurassic period, all of these rocks were intruded by batholiths of granodiorite, gabbro and serpentine. This complex of folded and intruded rocks is thinly veneered by nearly horizontal strata of Cretaceous and Tertiary age. The Tertiary beds consist partly of lava flows and breccia.

The ores occupy a series of parallel fracture zones or "stringer lodes" as they are locally called. In some places there are several such zones parallel with each other but several kilometers apart. Altho no single lode has great length, they overlap each other, and altogether the belt in which they occur is more than 110 kilometers long in a northwest-southeast direction. The veins change in richness from point to point, either horizontally or vertically, and there seems to be no general principle governing these variations. The ore generally consists of quartz and pyrite associated with free gold. In some mines tellurides have been found, but they are not widely distributed.

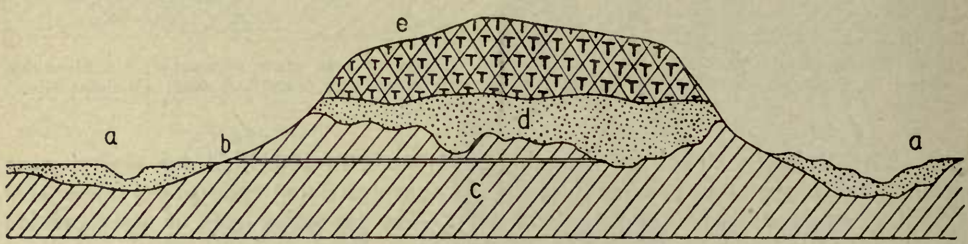

Fig. 70. Diagram of the occurrence of gold-bearing gravels northwest of Sacramento, Calif.: a, terraces in recent gold-bearing gravel; b, mouth of mine tunnel; c, pre-Cretaceous folded and schistose rocks; d, Tertiary gold-bearing gravel and sand; e, eroded remnant of lava flow. (After Branner and Newsom.)

The Mother Lode ores, like those of the Cripple Creek district, are thought to have been deposited in fracture zones by hot solutions from below. The source of these solutions was doubtless the adjacent igneous intrusions, chiefly of granodiorite, which accompanied the late Jurassic deformation.

Placerville, California, District.[1] This is one of many localities in California where gold has been mined from deposits of gravel of either Tertiary or recent age. Here, as in most other parts of the state, the gold-bearing deposits are of several ages and found in several different situations.

Some of the richest deposits are in the channels of early Tertiary rivers flowing westward from the Sierra Nevada. The source of the gold was apparently the gold-bearing fissures of the Mother Lode and similar districts. The gold accumulated in the bottoms of the channels, chiefly next to the bed rock. In later Tertiary times, probably late Miocene, volcanic eruptions near the crest of the range produced extensiv lava flows and thick deposits composed of andesitic, rhyolitic, and basaltic materials.

[1] Placerville, Calif., folio (No. 3). Geol. Atlas U. S., U. S. Geol. Survey, 1894.
Colfax, Calif., folio (No. 66). Geol. Atlas U. S., U. S. Geol. Survey, 1900.
Nevada City Special, Calif., folio (No. 29). Geol. Atlas U. S., U. S. Geol. Survey, 1896 and others.

The gold-bearing gravels in the valleys were buried beneath these volcanic deposits and have thus been preserved until the present. The divides between the streams, being more easily eroded than the lava, have been worn away more rapidly, so that the old gravels, with a part of the lava, are now found on the tops of ridges, between the more modern canyons. By means of tunnels excavated underneath the lava-capping, these elevated, ancient river beds have been explored and thus some of the richest gold-bearing gravels have been discovered.

Gold is found also in the sand and gravel at the bottoms of the present canyons. Much of this gold is doubtless derived from the same source as that in the Tertiary deposits, while another portion of it doubtless represents the workt-over Miocene placers themselves. In the early days of California, nearly all of the gold was obtained from the recent placer deposits, which were mined by the hydraulic method. The mining of these gravels has since greatly declined and now most of the deposits are abandoned. Along some of the larger rivers, as at Oroville, the use of large stream dredges has been found to be profitable, but their use is not practicable in most situations.

There are numerous other placer deposits,—some still being workt,—in the states of Idaho, Montana, Colorado, Oregon and to a less extent in other parts of the West. Some placer gold is obtained in Georgia and North Carolina in the southeastern part of the United States, but the amount is very small.

Silver.

Modes of occurrence. The occurrence of silver ores in the United States is in general much like that of gold, but there are certain distinctiv differences. Silver occurs much more rarely in the nativ state than gold, most of it being obtained from sulphides and other compounds. Unlike gold, also, silver is rarely found in placer deposits, and nowhere in the United States are placer sediments mined expressly for the silver contained. The commonest ores of silver are argentite, silver-bearing galena, cerargyrite and nativ silver, but it is found also in a variety of other minerals such as proustite, pyrargyrite and tetrahedrite. There are but few places in the United States where silver is mined alone. A considerable proportion of the production of all the silver mines in this country consists of either gold, copper, lead or zinc, or some combination of these.

Distribution.

Geographic. The only important silver deposits in the United States are found in the western mountain districts. There they are largely confined to the Rocky Mountain states, such as Colorado, Utah, Idaho, and Montana. Nevada, however, has a noteworthy production of silver, and small quantities come from California and other Pacific states.

Silver ores are found in insignificant quantities in eastern United States. It constitutes a by-product in the great copper mines on the south shore of Lake Superior,—the only place east of the Rocky Mountains where silver is mined in noteworthy quantities.

Stratigraphic. The relation of silver to rocks of different ages is much the same as that of gold. It is even more closely related to the Tertiary volcanic rocks in the West.

Typical silver districts.

The San Juan, Colorado, District.[1] Groupt in and around the San Juan Range in southwestern Colorado there are several mining districts of importance. These

[1] Ouray, Colo., folio (No. 153). Geol. Atlas U. S., U. S. Geol. Survey, 1907.
Telluride, Colo., folio (No. 57). „ „ „ „ „ „ 1899.
Silverton, Colo., folio (No. 120). „ „ „ „ „ „ 1905.
Rico, Colo., folio (No. 130). „ „ „ „ „ „ 1905.

separate localities are called the Ouray, Telluride, Silverton and Rico districts. The chief product is silver, but the ores are complex and yield a variety of metals.

The rocks of the San Juan district consist of gently folded Cretaceous and Paleozoic rocks with small exposures of pre-Cambrian formations. These are partly covered by an unconformable succession of Tertiary volcanic flows, breccias and tuffs, 600 to 2100 meters thick, which comprise a variety of lavas, such as rhyolite, andesite and basalt. Thru all of these terranes stocks and dikes of monzonitic and other porphyries have been intruded.

Fig. 71. Distribution of silver mines in the United States in 1908. (Modified after F. L. Ransome).

The ores are contained in well defined fissures or systems of interlocking fissures, some of which are remarkably persistent horizontally. The Smuggler vein has been mined continuously for a distance of two miles, and there are others of comparable length. Where these veins intersect limestone there are frequently extensiv replacement ore bodies, but the well defined fissure veins are more characteristic of this district.

The ores of the San Juan district contain a great variety of minerals. Among the chief metallic compounds are galena, freibergite, sphalerite, pyrargyrite, proustite, chalcopyrite, and argentite. Copper and gold are found partly in the free condition. The chief gangue mineral is quartz, but in some veins there are large quantities of rhodocrosite, barite, and calcite. Many comparativly uncommon minerals, such as sulpharsenates and other complex sulphur compounds, occur in small quantities.

In general the ores seem to have been produced by solutions from intrusions of monzonite porphyry of Miocene or later age. The fissure walls are generally altered to brilliant red and orange colors and contain an excess of sericite, kaolin, and other aluminous minerals. With these are particles of pyrite, some of which contain gold.

Among these complex ores, silver is in some cases almost the sole product in some mines, while in others it is comparativly uncommon. The average value of the ore is 65 to 900 dollars per metric ton, but some small bodies are much richer.

The Cœur D'Alene, Idaho, District.[1] This district is the largest producer of lead in the United States, but it also yields large quantities of silver and for that reason is described in this connection.

The older rocks are folded quartzites and slaty shales, believed to be of late Algonkian age. These have been faulted to some extent at a much later time and are intruded by bosses and dikes of monzonite, thought to be off-shoots of the great central Idaho batholith of granitic rocks. In addition there are dikes of diabase and lamphrophyre. The ores of the district yield lead and silver in proportions of about 200 to 1 by weight. Formerly considerable gold was obtained from placers, and one prominent copper deposit is now being mined. The ore bodies are irregular replacements of the siliceous strata along zones of fracturing and faulting. Near the monzonitic intrusions the ore bodies are especially irregular and penetrate farther from the fissures with which they are associated.

The metallic mineral of chief importance is argentiferous galenite. Near the contact between the monzonite and the sedimentary rocks this is associated with several other sulphides, such as sphalerite, pyrite, and pyrrhotite, and with the silicates, biotite, diopside, and garnet. In these situations the wall rocks are considerably metamorphosed, and the outlines of the ore bodies are indefinit.

Farther away from the igneous contacts,—in some cases several kilometers from known contacts,—the galenite is found in better defined fissure veins and is associated with a gangue consisting chiefly of siderite, with subordinate sulphides and none of the pyrogenetic silicates.

According to Ransome, all of the ores have probably been deposited by hot ascending solutions, which had their source in the monzonite stocks beneath. The change in the character of the ore is thought to be due to changing conditions of temperature and pressure outward from the intrusiv mass,—the sulphides with complex silicates having been precipitated near the intrusion, while the sideritic deposits were made by solutions which wandered far out into the country rock.

Up to 1905 the mines of the Cœur D'Alene district had produced nearly 1700 metric tons of silver and about 900000 metric tons of lead. The value of the total production of both metals in recent years has averaged 10000000 to 15000000 dollars per year.

Large quantities of silver are obtained from lead ores in other parts of the United States, notably in the Leadville[2] and Aspen districts of Colorado, the Tintic[3] region of Utah, and at Eureka[4], Nevada. While each of these districts has its own peculiar geological succession, structure, and conditions, the occurrence of the ores is not very unlike that in the Cœur D'Alene region.

The Presidio Mine, Texas. The Presidio mine, and adjacent prospects, are situated in the Franklin mountains in the western corner of Texas. Altho a comparativly unimportant mining district, this will serve as an example of a class of silver deposits which is found especially in the southwestern states, and is even more common in Mexico. These are commonly known as "horn silver" deposits.

The ores occur chiefly in the form of irregular replacements in a pure Permian limestone. The larger bodies are connected with small veins, but the veins themselves are worth but little. The characteristic minerals of the ore are cerargyrite and galenite, with scattered crystals of calcite; all are imbedded in a highly siliceous gangue. In the

[1] Ransome, F. L., and Calkins, F. C. The Geology and Ore Deposits of the Cœur d'Alene district, Idaho. U. S. Geol. Survey, Prof. Paper 62, 1908.

[2] Emmons, S. F., Geology and Mining Industry of Leadville, Colorado. U. S. Geol. Survey, Mon. XII, 1886.

[3] Tintic Special, Utah, folio (No. 65). Geol. Atlas U. S., U. S. Geol. Survey, 1900.

[4] Hague, A., Geology of the Eureka District, Nevada, U. S. Geol. Survey, Mon. XX, 1892.

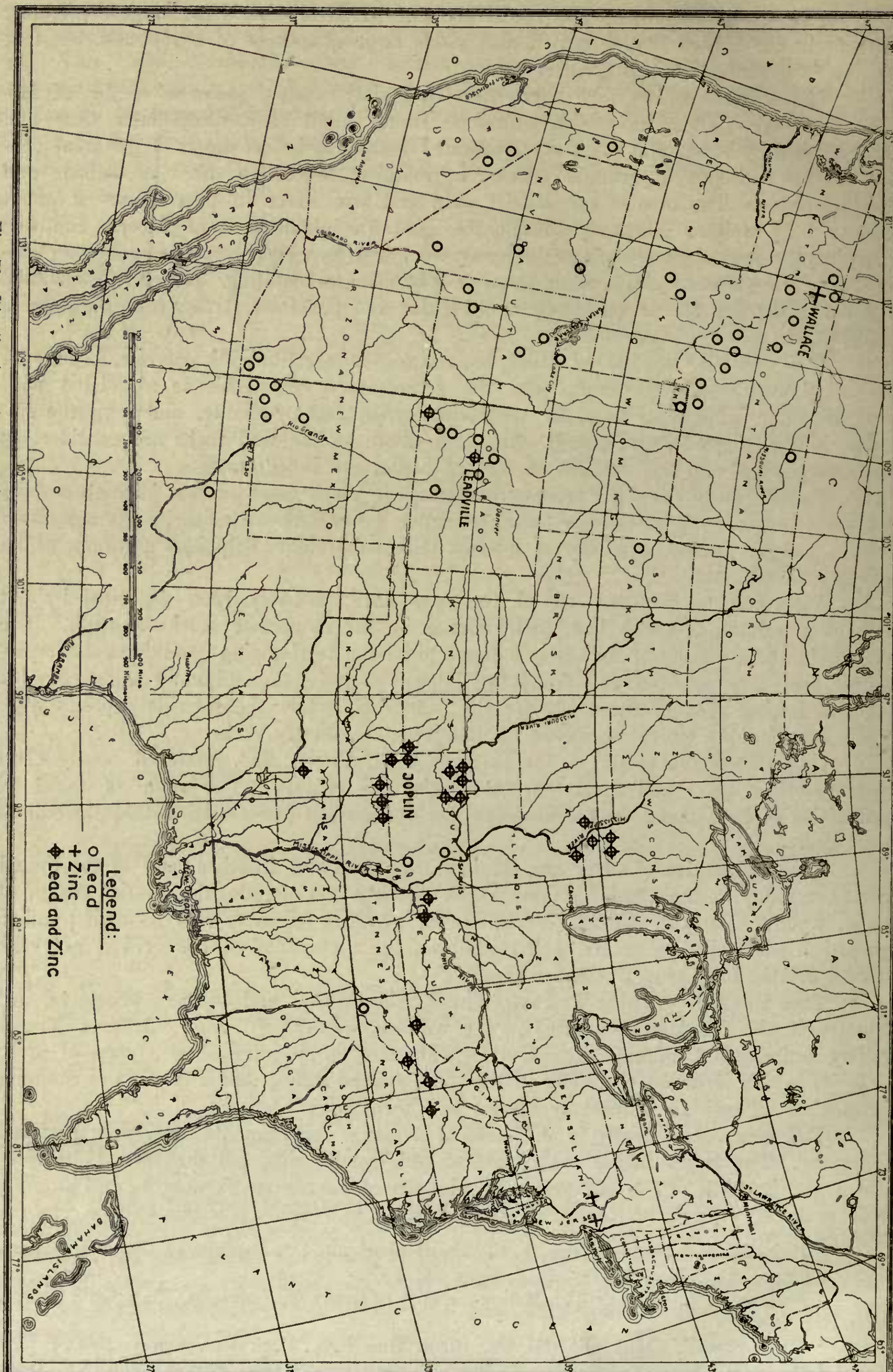

Fig. 72. Distribution of mines which produce lead and zinc in the United States. (Modified after F. L. RANSOME.)

oxidized portion of the deposits, cerussite, and occasionally malachite, are found associated with free silver.

The limestone is cut by dikes of andesite and rhyolite, which are in turn associated with surface volcanic rocks of Tertiary age. It is probable that these intrusions are the source of the solutions which deposited the ores, but such a relation has not been definitly traced.

Lead.

Modes of occurrence. In the United States lead is derived largely from sulphide ores and in small measure also from the carbonate (cerussite), which is found in the oxidized parts of such deposits. It sometimes appears alone in the form of galenite, but it is more often associated with sulphides of zinc or other metals, and in many districts silver is an important constituent of the ore.

The ore bodies are much like those of copper and silver, being either well defined veins or irregular replacement deposits. Some of these are evidently connected with igneous intrusions as in the Cœur D'Alene district; while in the Mississippi valley district igneous rocks have played no part in the production of the ores.

Distribution.

Geographic. The two greatest lead-producing districts of the United States are, in order of their importance, the Cœur D'Alene region in Idaho, and southern Missouri. There are other important lead deposits in Colorado, Utah, and a few in other western states. The upper Mississippi district, in the adjoining corners of Wisconsin, Illinois, and Iowa, was formerly a large producer of lead, and in the early years of the industry was much the most important source of the metal. At present, however, it produces less than 1 percent of the total output of the United States. In New England and some other eastern states, small veins of lead ore have been found, but from all of them combined no considerable amount of metal has been produced.

Stratigraphic. In the Cordilleran states the lead ores are found in rocks of various ages, chiefly Algonkian or Paleozoic, but in all cases they are more or less directly connected with intrusiv igneous rocks which in the Rocky Mountains are of Tertiary age but farther west are late Jurassic.

In southeastern Missouri and Wisconsin the ores are found in Ordovician limestones and even in the Cambrian, while in the Joplin region of southwestern Missouri it is the Mississippian limestone that contains the ore bodies.

Typical lead districts.

Southeast Missouri District. Most of the lead deposits in the United States are associated with ores of other metals, notably silver. There is but one locality in which large quantities of lead are found with almost no other metals. This is in southeastern Missouri. The rocks are chiefly limestones of Cambrian and Ordovician age, resting upon Cambrian sandstone. The beds are horizontal and broken by a few faults. The Cambrian sandstone rests upon pre-Cambrian granite and porphyry which have been previously mentioned in connection with the iron ores of Missouri (see p. 203).

The ore bodies are usually broad "blankets" of irregular thickness replacing the limestone at various horizons but especially near the contact with the underlying sandstone. The chief mineral is galenite, and with it there is more or less pyrite. These sulphides are disseminated in the limestone, very irregularly, and, as they grade off into the pure limestone, the limits of the ore bodies are poorly defined. The ore, as mined, usually contains only $^1/_{10}$ to $^1/_{20}$ of galenite, but small bodies of the nearly pure sulphide are not rare. A little silver (averaging about 30 grams per ton) generally

accompanies the lead and in one locality, at least, the galenite is associated with small quantities of other sulphides containing copper, nickel, cobalt and cadmium.

The origin of these and other lead ores of the Ozark region is still in dispute. Winslow[1] and others favored the hypothesis that they were deposited by descending solutions during the long period of weathering and reduction of the land surface from the Carboniferous period to the present. Buckley[2], on the other hand, argues that the ores have come from rising artesian solutions circulating thru the basal sandstone, and thus explains the rich deposits in the limestone immediately above. It is evident that the ores have been gradually introduced and have replaced the original limestone.

These are among the oldest lead mines in the United States, having been workt by white men for nearly 200 years, and previously by the Indians. At first the galenite was taken from shallow pits along the outcrops, but in more recent years nearly all of the ore has been mined from shafts, most of which are less than 120 meters deep. The mines are groupt in several scattered districts north and northwest of the St. Francis Mountains. In 1909 the production of lead in this district amounted to about 100000 metric tons, and it is now increasing.

Leadville, Colorado. The Leadville district[3] in central Colorado was at one time the chief lead-producing district of the United States; but it is now outrankt by the Cœur D'Alene mines, which have already been described under the caption of silver (see p. 221). The rocks at Leadville are Paleozoic limestone with subordinate shale and sandstone, resting upon pre-Cambrian crystalline rocks. The beds have been considerably folded and faulted, and are cut by intrusiv dikes and sheets of porphyry which appear to be of early Tertiary age.

The ore bodies are irregular replacements of limestone, generally along the lower sides of porphyry sills but also to some extent in cross-fractures near them. The ores contain silver-bearing galenite, associated with small quantities of the sulphides of copper and antimony and other accessory compounds of bismuth, molybdenum, arsenic, vanadium, etc. The gangue minerals are silica (chiefly in the form of chert), mixt with oxides of manganese and iron, and associated with more or less barite and amorphous kaolinic clay.

The unaltered sulphides have not been found in all of the mines. At first, and until recently, the miners workt only the oxidized portion of the ore deposits, where the prevailing minerals are cerussite, anglesite and some less common compounds. These oxidized ores have played a particularly important part in the smelting industry of the Rocky Mountains, inasmuch as they have been useful in the reduction of refractory ores from other districts.

The ore bodies are thought to have been originally deposits of sulphides brought into the limestones along fissures adjacent to the porphyry intrusions, and probably originating in hot igneous rocks farther beneath. The chief subsequent change in the ore has been that of the deep oxidation of the superficial portions of the deposits in the course of weathering and the downward circulation of surface waters. The primary ore deposits are evidently older than the numerous faults which divide the district into a series of blocks.

Lead-producing ores, carrying silver and usually gold, are found not only in the Leadville district, but at many other points in the Rocky Mountains and to a less extent in the Great Basin. Among the better known mining districts belonging to this

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[1] Winslow, A., Lead and Zinc Deposits, Missouri Geol. Survey, vols. VI, VII, 1894.

[2] Buckley, E. R., The Genesis of the Lead and Zinc Ores of the Mississippi Valley, Econ. Geol., II, pp. 427—433, 1907.

[3] Emmons, S. F., Geology and Mining Industry of Leadville, Colorado. U. S. Geol. Survey, Mon. XII, 1886.

class, are the Ten-mile district[1] not far from Leadville, the Aspen[2] district in central Colorado, the Tintic[3] region of Utah, and the mines in the Oquirrh Range in the same state. Mention has already been made of the rich and somewhat similar deposits of the Cœur D'Alene district in Idaho, and it may be said here that the ores of the Wood River district farther south in the same state are of similar character. Some of the ores in the Eureka district, Nevada, and other parts of the western states, are in general like those of the Leadville region.

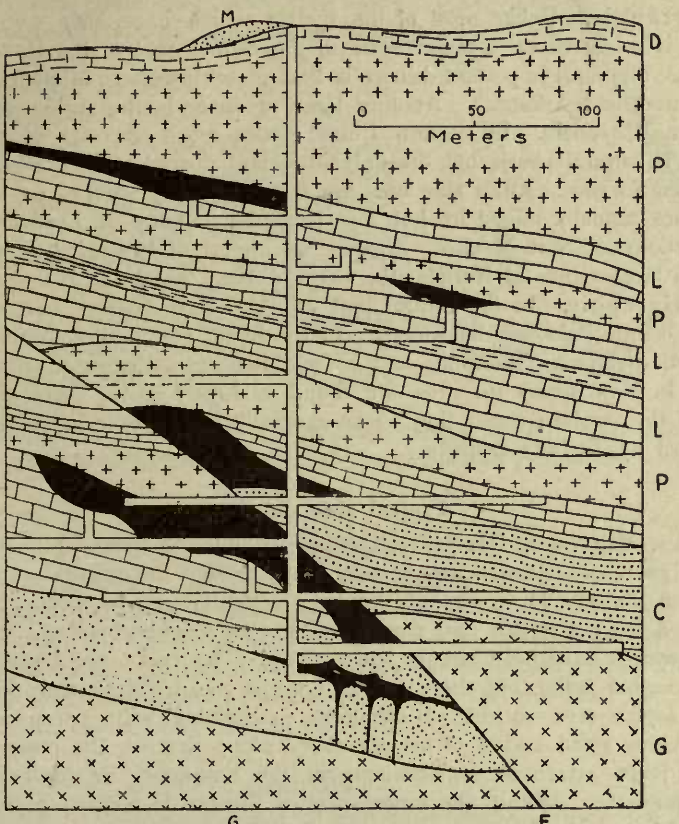

Fig. 73. Vertical section of a lead-silver mine near Leadville, Colo.: G, granite; C, Cambrian quartzite; P, porphyry intrusivs; D, decayed portion of porphyry; L, Paleozoic limestone. Ore bodies are represented in black. M, mine dump. (Argall.) (The dotted body on the left of the fault is the same Cambrian quartzite as C on the right).

Zinc.

Modes of occurrence. The occurrence of zinc is much like that of lead. It is found generally in veins but sometimes in the form of irregular replacements in limestone and other alterable rocks. Most of the metal produced in the United States is derived from sphalerite, smaller quantities coming from the silicates and carbonate of zinc. It is often associated with lead ores, either as a subordinate or as a dominant constituent. Thus in southeastern Missouri rich lead ores contain small quantities of

[1] Ten-mile District, Colo., folio (No. 48). Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[2] Spurr, J. E., Geology of the Aspen Mining District, Colorado. U. S. Geol. Survey, Mon. XXXI, 1898.

[3] Tintic Special, Utah, folio (No. 65). Geol. Atlas U. S., U. S. Geol. Survey, 1900.

zinc, while in the southwestern part of the same state small quantities of lead are found with the bodies of zinc ore.

In the western mountains it is common as a minor constituent of ores which are mined primarily for copper, gold or silver. The western zinc ores are almost always closely associated with igneous intrusions, but those in the Mississippi valley have no such relation.

Distribution.

Geographic. Unlike most of the metals which have been noted in previous pages, zinc is produced on a larger scale in the central part of the United States than in the West. The most important district is that of southwestern Missouri, with adjacent parts of Kansas and Arkansas. Another large producer is the region centering about southwestern Wisconsin. In eastern United States small deposits of zinc ores have been found in several places but the only important district is in northern New Jersey, near Franklin Furnace. Altho zinc ores are found in many parts of the western mountains they are actually mined in but few localities, notably at Leadville in Colorado and in portions of New Mexico. Zinc as an important by-product is recovered from some of the large mines of Nevada, the Cœur d'Alene district of Idaho and elsewhere.

Stratigraphic. In the central part of the United States, zinc ores are associated with certain Paleozoic limestones. In the Joplin region of southwestern Missouri, it is the Mississippian limestone, and in southwestern Wisconsin, upper Ordovician limestone. In New Jersey the ores are found in highly folded rocks of pre-Cambrian age, and in the western states they occur generally in Paleozoic limestones which have been intruded by Tertiary eruptivs.

Typical zinc districts.

Joplin, Missouri, District. The region centering about Joplin, Missouri[1], with neighboring parts of Arkansas and Kansas, is at present the greatest producer of zinc in the United States. The rocks of this region are horizontal beds of Mississippian limestone and Pennsylvanian coal measures. In the neighborhood of the zinc mines the coal measures have been largely worn away. The rocks are traverst by fissures and a few normal faults, but there are no igneous rocks within many kilometers.

The Joplin ores consist of sphalerite, associated with pyrite and crystalline dolomite. Altho small bodies of ore are found along fissures, the more productiv ore deposits are large cavernous replacements in the limestone, or form the matrix in brecciated limestone. Within the larger masses the ore is relativly pure, but on the margins it may grade off imperceptibly into limestone.

The origin of these ores is still in dispute. According to Van Hise and Bain[2], they were probably brought from the Cambro-Ordovician rocks of the Ozark plateau, carried in solution by outward moving artesian waters, and deposited along fractures in the Joplin region as these waters rose and came in contact with the organic matter so prevalent in the vicinity of the coal measures. Buckley[3], on the other hand, finds the Pennsylvanian coal measures the source of the ore and thinks it was deposited in the fracture zones of the subjacent limestone by downward circulating waters.

The ores are mined from shafts, scarcely any of which exceed 60 meters in depth. Below the general level of ground water, the sulphide ores predominate. Above

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[1] Joplin District, Mo., folio (No. 148). Geol. Atlas U. S., U. S. Geol. Survey, 1907.

Buckley, E. R., and Buehler, H. A., Geology of the Granby area, Missouri Bur. of Geology and Mines, Vol. 4, 2nd ser., 1906.

Van Hise, C. R., and Bain, H. F., Lead and Zinc Deposits of the Ozark Region, U. S. Geol. Survey, Ann. Rep. 22, pt. 2, pp. 23—228, 1901.

[2] Loc. cit. — [3] Loc. cit.

that level there are considerable quantities of the carbonates (smithsonite and cerussite) with the silicate (calamine). At present, the sulphide zone supplies nearly all the ore mined.

The Franklin Furnace, New Jersey, District.[1] In northern New Jersey there is a small group of mines the ores of which are unique. They are complex, consisting chiefly of franklinite, willemite and zincite, intimately mingled with calcite and with more or less garnet, tephroite, and rhodonite. The ores have a granular texture and seldom furnish good crystals of the minerals.

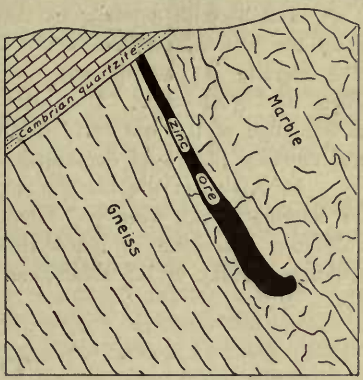

Fig. 74. Profile of a zinc ore body at Franklin Furnace, New Jersey. (U. S. Geol. Surv.)

The ore bodies are thick sheets of tolerably uniform dimensions embedded in crystalline limestone which is associated with gneisses thought to be of sedimentary origin. The rocks are closely folded and lie unconformably beneath lower Cambrian quartzite. The ore bodies take the form of sharp synclines, but unlike the rock strata they thin out to feather edges. It is thought by Spencer that the ore was introduced along curved bedding planes after the folding of the rocks took place. They have doubtless been metamorphosed since they were deposited.

Formerly iron from magnetite was produced in considerable quantity in this district, but at present zinc, with manganese as a by-product, is of chief importance.

Aluminum.

Modes of occurrence. Altho some of the aluminum produced in the United States is made from imported cryolite ores, nearly all of the local deposits mined consist of bauxite. This is found generally in the form of irregular residual deposits associated in some cases with faults and in others with igneous rocks. Generally the ore is more or less mixt with clay and sand. All of the ores thus far used are at or near the surface and are mined from open pits.

Distribution.

Geographic. Altho the deposits of bauxite in Arkansas have not been known as long as some of those in the Appalachian region they now produce much more ore than any other district. Second in rank comes Alabama with adjacent portions of Georgia and Tennessee. Other deposits of bauxite have been found in Pennsylvania, Virginia, New Mexico and California, but none of these had yielded much ore before 1907.

Stratigraphic. Most of the bauxite deposits appear to be of comparativly recent age. In the southern Appalachians they lie upon Cambro-Ordovician limestone, but are obviously much younger than the period of folding at the close of the Paleozoic era. At one point in Georgia the ores are definitly within the horizontal Comanchean beds, and in Arkansas they are associated with early Tertiary strata. Most of the deposits seem to have no definit relation to igneous rocks, but in Arkansas they are always associated, so far as known, with syenites which are slightly older than the Tertiary beds in which the ores are found.

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[1] Franklin Furnace, N. J., folio (No. 161). Geol. Atlas U. S., U. S. Geol. Survey, 1908.

A typical aluminum district.

Little Rock, Arkansas, District. In this region the rocks are folded Paleozoic strata intruded by irregular bosses of syenite apparently of late Cretaceous or early Tertiary age. The hard rocks are covered and envelopt on all sides by soft Tertiary sandstones and clays.

The bauxite deposits are found in the form of irregular structureless sheets resting upon the uneven surface of the syenitic rocks and covered by the Tertiary sandstones. The bauxite is pisolitic and the individual nodules are mixt with more or less clay, silica, and iron oxide. Branner[1] inclines to the hypothesis that the ores were formed at the edge of the sea early in the Tertiary period by hot solutions rising from below and causing the rapid decomposition of the aluminous syenites.

In Alabama the bauxite deposits differ from those in Arkansas in that there are no igneous rocks nearby. The ores rest on the eroded surface of folded and faulted Paleozoic limestone and are thought to be residual accumulations derived from the prolonged decay of the limestone.

The Lesser Metals.

The metals remaining to be described are produced in but small quantities in the United States. Of each, therefore, only a brief description will be given. For distribution see map, Fig. 211.

Quicksilver (Mercury). Less quicksilver is now mined in the United States than in the later decades of the last century. This is due partly to the decrease of gold placer mining, in which a large part of the mercury was used, and partly to the exhaustion of many of the rather small deposits of quicksilver ores. In 1908 the production amounted to but 19753 flasks (= about 672000 kilos).

In the United States, as elsewhere, the chief ore of mercury is the sulphide (cinnabar). The mineral has been found in quantity only in the western states and has been mined chiefly in California and western Texas.

The California Mines[2] have always been the most productiv. They are scattered along the Coast Ranges both north and south of San Francisco. The ores, consisting of cinnabar, some metallic mercury and tiemannite (mercuric selenide), are found in irregular veins without important replacements of the wall rocks. The gangue minerals are chalcedony, dolomite, calcite, and pyrite, with some rarer compounds. Most of the veins intersect metamorphosed pre-Cretaceous rocks which are partly igneous and partly sedimentary in origin. Others are found in the unaltered and but moderately folded Cretaceous beds. It is believed that the ores are of late Tertiary age, and that they are related to the prevalent rhyolitic or basaltic intrusivs of the Coast Range.

In the Terlingua and adjacent districts along the Rio Grande in western Texas[3], quicksilver deposits have been discovered more recently and are now mined on a small scale. With the usual cinnabar are associated considerable quantities of three oxychlorides of mercury discovered here for the first time. The ores occupy veins and irregular caverns in Comanchean limestone and shale. In some of the caverns the ore is found mixt with calcitic stalactites and cave earth. The original deposition of the ores is related to adjacent intrusions of andesite, rhyolite and phonolite.

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[1] Branner, J. C., Bauxite Deposits of Arkansas. Journ. of Geol., vol. 5, 1897, pp. 263—289.

[2] Becker, G. F., Geology of the Quicksilver Deposits of the Pacific Slope. U. S. Geol. Survey, Mon. XIII, 1888.

[3] Turner, H. W., The Terlingua Quicksilver Deposits. Econ. Geol., vol. 1, 1906, pp.265—281.
Philips, J. B., The Quicksilver Deposits of Brewster County, Texas. idem pp. 155—162.

Small quantities of mercury ores are mined in central Utah, and there are scattered deposits in Oregon, Nevada, and Arizona, from which very little has been sent to market.

Antimony. Antimony has been found in a few places in the United States either as stibnite or in the form of antimonial lead ore. The only mines producing in 1909 were those in Idaho, Nevada, and Utah. Deposits which are either unworkt, or have not yet reached the productiv stage, have been discovered in Oregon, central Washington, California, and Arkansas.

Less than one-sixth of the antimony produced in the United States comes from the stibnite ores. The rest, amounting in 1907 to more than 1450 metric tons, is contained in antimonial lead. Inasmuch as this is used directly as an alloy, the two metals are not generally separated.

Manganese. Small quantities of manganese ores have been found widely distributed thruout the United States, especially in the mountainous districts. Most of the deposits now mined are situated in the Appalachian Mountains and Piedmont belt of eastern United States, in Arkansas and in California. The ore commonly occurs in the form of residual deposits associated with clay, lying upon the surface of weathered rock. In California there are veins of silicates and oxides of manganese, and in Colorado manganiferous silver ore is mined. The manganiferous zinc ores of New Jersey have been noted (see p. 227). Much of the manganese-bearing ores of the country are not reduced to the metal but are used in various metallurgical processes such as smelting and in the manufacture of spiegeleisen and manganese steel. The total production of the metal manganese in the United States amounted to only about 5500 metric tons in 1908, and in 1909 was much less.

Tungsten. The production of tungsten in the United States has rapidly increast from 42 metric tons in 1900 to 1490 in 1907. The production in the latter year greatly exceeded that of any other country.

The principal known tungsten deposits of the United States are situated at Boulder, Colorado[1], and in San Bernardino county, California. Smaller quantities of the metal have been mined at Wallace, Idaho, and at various points in Montana, Washington, Nevada, South Dakota, and Arizona. The ores generally occur in veins much like those of silver and other metals, but small quantities are found in gold placer deposits. Wolframite and scheelite are the most important compounds of tungsten found in the ores, but in a few localities hübnerite is important.

Platinum. The production of platinum in the United States increast considerably in the early years of the 20th century, probably because of the rapid rise in the price of the metal. In 1906, 44 kilos were sold, but in 1907 the production decreast to 11 kilos.

Nearly all of the platinum-bearing deposits of the United States are on the Pacific coast and chiefly in northern California.[2] The metal is derived from grains and nuggets washt from streams and from beach sand or gravel. The nuggets contain not merely platinum but iron, iridium, palladium, rhodium, etc. Little if any platinum is taken from veins in this country.

Arsenic. Altho arsenic is mined for its own sake in but few if any localities in the United States, it is a rather common minor constituent of many ores of copper, silver, and gold in the western states. In the process of smelting these ores, important

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[1] Lindgren, W., Some Gold and Tungsten Deposits of Boulder County, Colorado. Econ. Geol., vol. 2, 1907, pp. 453—463.

[2] Day, David T., Notes on the Occurrence of Platinum in North America. Am. Inst. of Min. Eng., Trans. vol. 30, 1901, pp. 702—708; and Black Sands of the Pacific Coast. Mining World, vol. 27, 1907, pp. 891, 974, and 1013.

quantities of arsenic and arsenious oxide are recovered at Anaconda, Montana, and Everett, Washington. With proper care and facilities, much larger amounts of arsenic could be saved in the reduction of various metallic ores elsewhere.

Other subordinate metals. Of the following metals only very small quantities are produced in the United States. The mining of most of them has been sporadic and dependent partly upon current prices of the metals.

Tin. Tin has been found in small quantities near the contacts of granite bosses in the Black Hills of South Dakota[1], southern California, and more recently near Spokane, Washington.[2] As "stream tin" it is known also in parts of Idaho, Montana, South Dakota, and in eastern United States in North and South Carolina. At several points in the Piedmont slope cassiterite occurs in veins in gneiss, but in quantities too small to be minable. For many years no tin has been produced in the United States, but in 1907 about 56 metric tons of the metal were sent to market.

Nickel and Cobalt. At present nickel is produced in only two localities in the United States, altho nickeliferous ores are known to occur in a few other places. In southeastern Missouri nickel and cobalt are obtained as by-products in the smelting of ores; and in central Oregon a small body of nickel ore has recently been opened. Small quantities have been found in the ancient rocks of the Piedmont province along the Atlantic slope but they seem to be of little value.

Molybdenum. Altho small deposits of molybdenum ores are widely scattered in the United States, very few of them are actually mined. They are known near Lake Chelan, Washington, at Alta, Utah, at Corona, California, and in some other western states, as well as in Maine. Most of the ores consist of wulfenite or molybdenite.

Titanium. Titanium occurs in relativly large quantities as a constituent of igneous rocks, but it is rarely found concentrated in minable quantities. In the United States the only productiv mines of titanium ore are in Chester County, Pennsylvania, and in Nelson County, Virginia. In the latter place rich pockets of rutile have been found in large pegmatite dikes.

Bismuth. Bismuth ores in small quantities have been found associated with the ores of other metals in most of the western mountain states. In 1906 over 3700 kilos of bismuth were produced by the mines of Leadville, Colorado, but in the succeeding year none seems to have been sold. It is recovered only as a by-product in the smelting of the ores of more valuable metals.

Cadmium. The zinc ores of the Joplin district in southwestern Missouri are known to contain on the average about one third of 1 percent of the metal cadmium, and the fact is evidenced by films of greenockite coating the crystals of sphalerite in some of the ore bodies. Altho most of it is lost, about 15 percent is recovered in the process of smelting.

Vanadium. Small quantities of vanadium ores have been found in recent years in Colorado, New Mexico, Arizona, and Montana. In 1907 a small quantity valued at about 6000 dollars was mined in southwestern Colorado from ores which contained roscoelite and carnotite, with a little vanadinite.

Tantalum. Small quantities of tantalum ore have been produced from time to time in South Dakota and North Carolina, but the deposits are very small.

Uranium. Uranium is one of the constituents of carnotite, which is mined on a small scale at several points in southwestern Colorado. Other deposits of uranium ores have been found in adjacent states but of these none appear to be utilized.

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[1] Irving, J. D., and others, Economic Resources of the northern Black Hills. U. S. Geol. Survey, Prof. Paper 26, 1904.

[2] Collier, A. J., Tin Ore at Spokane, Wash. U. S. Geol. Survey, Bull. 340, 1908, pp. 295—305.

Rare Earths. Many minerals containing the rare earth elements (cerium, thorium, erbium, yttrium, ytterbium, lanthanum, etc.) have been found in small quantities in the United States, particularly in the mountains of western North Carolina and in Llano county, Texas. Monazite is the only one of these minerals that is regularly mined. The output, valued in 1908 at about 50000 dollars is used chiefly in the manufacture of thorium nitrate. The monazite is a constituent of schistose rocks, but in North and South Carolina, where it is mined, it is obtained from placer workings in stream gravels.

The Texas deposits, altho commercially of little importance, are of great interest because of the variety of unique or very rare minerals there found.

B. The Fuels and other Bituminous Products.

Coal.

Modes of occurrence. In the United States coal is as varied in composition, structure and occurrence as in other countries. As elsewhere, it occurs in lenticular beds or seams in sedimentary rocks. There are all grades from peat, thru brown coal, lignite, bituminous coal, and anthracite, to graphite. The anthracite is restricted to a few small localities, but the product of the mines is nevertheless large. Bituminous coal of varying quality is widely distributed. There is an even greater quantity of lignite, but this is not yet mined extensivly.

In the quantity of coal produced the United States exceeds all other countries. In 1909 the total production was about 418 million metric tons, valued at more than 554000000 dollars at the mines. Of this quantity about $17^2/_3$ percent was anthracite.

Distribution.

Geographic. The distribution of coal deposits in the United States is shown on the accompanying map. The most important fields are in the eastern half of the country. The great central interior region stretching from Texas and Oklahoma northeastward to the Appalachian Mountains includes three large and several smaller coal fields. Perhaps these were formerly connected, but have been separated by subsequent erosion. The strata in these fields are but little folded and the coal is bituminous. There is some anthracitic coal, however, in the folded beds of Arkansas. In the much smaller and isolated field of northeastern Pennsylvania the coal is anthracite. In the West, coal is widely distributed in the Rocky Mountains, particularly in the states of Colorado, Wyoming, and Montana. There are in this region many small coal fields, which are separated by large areas of barren rocks.

In addition to these most important districts there are many minor deposits of coal scattered thruout the country. In Michigan a synclinal basin contains several valuable seams of bituminous coal. In Rhode Island graphitic anthracite, almost too hard to be of commercial value, occurs among the highly folded beds. Near the Atlantic coast, in Virginia and North Carolina, there are small coal deposits in the Triassic rocks. The Eocene strata of the Gulf coastal plain contain beds of lignite usable as fuel. In Washington rich coal deposits of fairly good bituminous grade abound in the Puget Sound region, and there are others of less value on the eastern slope of the Cascade range. Many other small deposits of various ages are scattered thruout the West.

Stratigraphic. In the United States, as elsewhere, coal is found in strata of many different ages. Altho thin coaly layers have been reported from the Devonian beds of Maine and are found in the Mississippian formations of Pennsylvania, little if any coal has yet been mined in the United States from rocks older than Pennsylvanian (upper Carboniferous). In the United States the latter system, as in Europe, contains

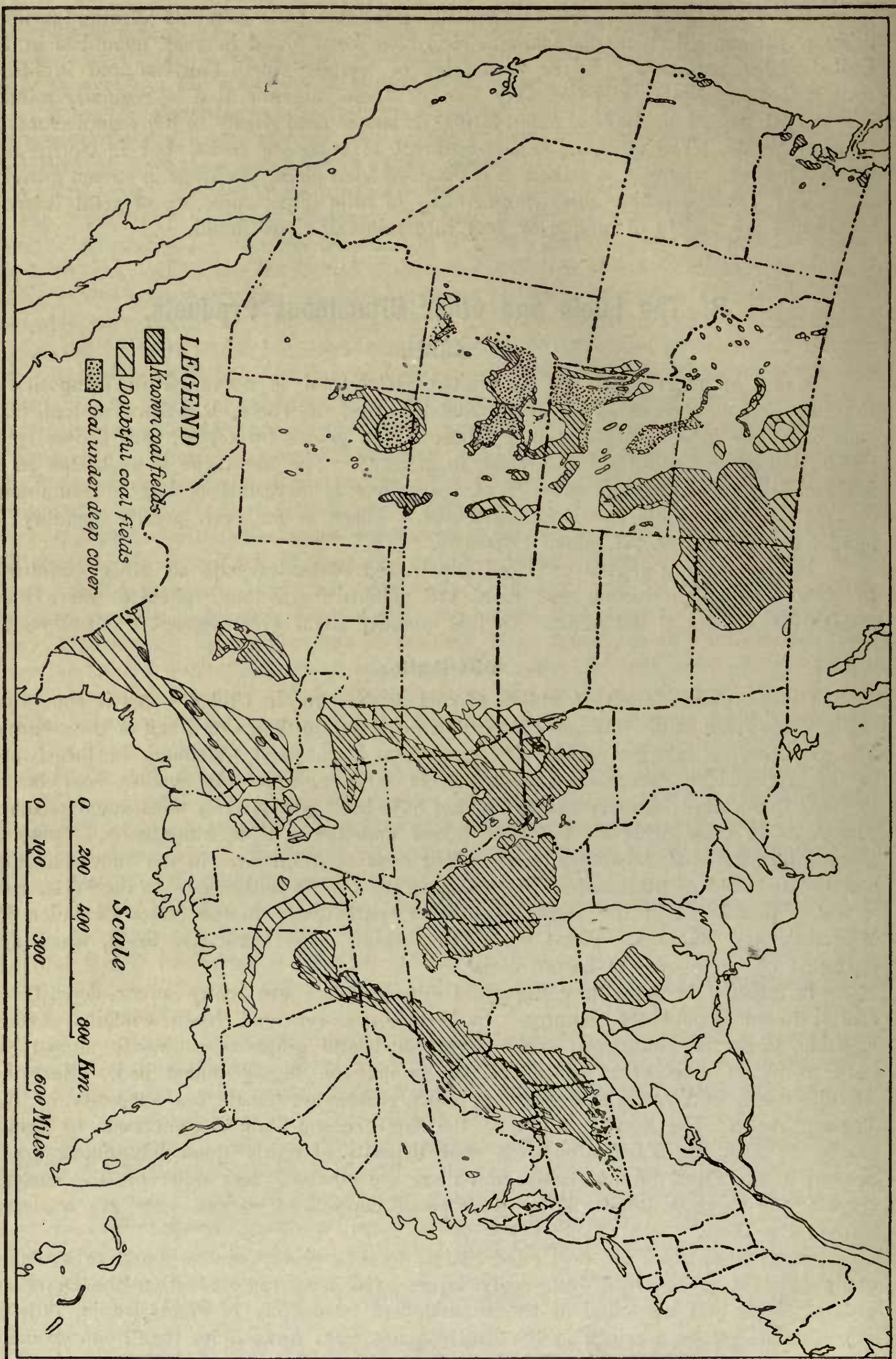

Fig. 75. Sketch map showing the distribution of coal fields in the United States. (After M. R. Campbell and E. W. Parker, U. S. Geol. Surv.) — The Coal fields of the central and eastern states are of Pennsylvanian age; those near the Gulf of Mexico are chiefly of Eocene age; and the Rocky Mountain fields are chiefly Cretaceous.

by far the largest deposits of the better grades of coal. The Carboniferous coals lie in the central and eastern states, while the western coals are younger.

The Triassic rocks of the Piedmont belt in Virginia and North Carolina contain small coal seams.

In Montana and the adjacent edge of South Dakota, the Comanchean (Lower Cretaceous) system contains some valuable coal deposits. The most important western coal deposits are, however, in the late Upper Cretaceous and basal Eocene formations. In the Great Plains and Rocky Mountains these strata contain many seams of coal in which the quality varies from lignite to bituminous coal and, near volcanic intrusions, even to anthracite. Eocene-Oligocene coals are of considerable importance in western Washington. There scores of coal seams, many of which are large, are gently folded. Coal or lignite of poorer quality is found also in the Eocene beds of Oregon, on the east side of the Cascade Mountains in Washington, and in the central Gulf states.

Later Tertiary coals have been found at several points in the western states but nowhere do they appear to be commercially important.

Typical coal districts. There is not space to describe even the more important coal districts of the United States. A few examples have been selected as typical of certain classes of coal deposits to show the range of quality and conditions found among them.

The Pittsburg District.[1] Western Pennsylvania, within which is the city of Pittsburg, is the most important coal mining district in the United States. The rocks are horizontal beds of Pennsylvanian age, consisting of alternate sandstones, dark shales, and thin limestones, with coal beds at many horizons. Most of the coal is found in the upper and lower parts of the system, the middle division being known to the miners as the "barren measures".

The Pennsylvanian rocks are divided into four series. The lowest (Pottsville) formation, consists largely of conglomerate and sandstone, but locally it contains several coal beds of some commercial importance.

The Alleghany series, formerly called the "Lower Productive Measures", contains 6 to 7 coal seams with associated beds of fire clay. Not all of these beds are of workable thickness in any one place, but 2 or 3 of them are generally minable. The beds average about one meter in thickness, but some exceed that.

The Conemaugh formation contains but little coal; locally 1 or 2 seams are workable, but the greater part of the formation consists only of shale, sandstone and limestone.

The uppermost series, called the Monongahela or "Upper Productive Measures" is generally similar to the Alleghany formation, and contains 6 coal seams, of which 2 are usually workable. The average thicknesses range from 1 to 3 meters, and the coal is associated not only with fire clay, but with some beds of carbonate iron ore. Of the Monongahela coal seams, the most renowned is the Pittsburg seam, which maintains an average thickness of two meters over an area about 80 kilometers in diameter. This coal is of the best quality and is used for a wide variety of purposes, not the least important of which is the manufacture of coke for the smelting of iron ores.

The coal seams of the Pittsburg region are exposed on the sides of skeleton ridges and are generally mined by means of tunnels driven horizontally into the hillsides.

The rest of the Appalachian coal field, from Pennsylvania to Alabama, is characterized by much the same conditions as in the Pittsburg district. The coal seams vary in number and position, and farther southwest the upper formations have

[1] See reports of the Pennsylvania Geological Survey and folios of the U. S. Geol. Survey

generally been eroded off. In the northern part of the field the average thickness of good coal in the entire system is about 21 meters. Maximum measurements are considerably greater.

The Pennsylvania Anthracite District.[1] The anthracite coal deposits are separated from those of western Pennsylvania by broad outcrops of older rocks. They lie in the northeastern part of the state and occupy several elongate troughs which have a northeast-southwest trend. The rocks are equivalent to those of western Pennsylvania, but in this region they are much folded and somewhat broken by faults. Corresponding to this markt difference in degree of deformation the coal of this locality is anthracite. It is comparativly free from sulphur and is of good quality generally. Of the 10 to 20 beds of coal, workt in this district, the largest and best known is the Mammoth vein, which has an average thickness of 6 to 8 meters and at one point is nearly 40 meters thick.

Owing to the folded condition of the beds, the coal can not be mined entirely from horizontal tunnels as in western Pennsylvania. Shafts with lateral drifts are generally used in the anthracite mines. The total production of anthracite in this district in 1907 was more than 77000000 metric tons. The rate of production has been rapidly increasing for many years and shows no sign of decline except for short temporary periods.

Central Arkansas District.[2] The rocks of this district are of the same general age as those in the Appalachian and intervening coal fields. It is suspected, however, that the coal-bearing portion here is early, rather than late, Pennsylvanian. The coal measures consist largely of shale, with beds of sandstone, and altogether they have a thickness of more than 1000 meters. In some portions of the field the rocks are but little folded, while in others they are considerably deformed. In the horizontal beds the coal is usually bituminous, but in the folded strata it is semi-anthracitic. Two principal seams of coal are recognized in this district. Where workable, they average 1 to 2 meters in thickness.

The productiv localities form a belt trending from east to west across the center of the state, on both sides of the Arkansas River,—the anthracite lying wholly in the southern belt, that is, in the Ouachita Mts. In 1907 the production of these two groups of mines exceeded 2300000 metric tons.

The broad coal fields of the central interior region and the Appalachian district, southwest to Texas, show many variations of detail, but are generally similar to the Pittsburg and northern Arkansas districts. The coal seams are fewer in number and seldom thick. They are contained in the Pennsylvanian system and the coal is uniformly of bituminous grade. Large quantities are mined in all the states in which the coal measures are exposed.

Raton, Colorado, District. The most productiv of several coal districts in Colorado lies near the southern edge of the state, and includes a portion of northern New Mexico. The coal-bearing rocks are of late Cretaceous age, and consist of sandstone and shale, with local intrusions of post-Cretaceous igneous rocks. From 1 to 3 seams of coal, with an average thickness of 1 to 2 meters, are mined. Most of the coal is of bituminous grade and some of it is suitable for making coke. The production in 1907 amounted to about 6000000 metric tons.

In some other parts of Colorado, as in Gunnison county, similar Cretaceous coals have been invaded by massiv intrusions of porphyry, which have changed the coals to anthracite and locally even to natural coke. The majority of the seams in the Rocky Mountains do not, however, yield a harder coal than bituminous.

[1] See reports of the Pennsylvania Geol. Survey.

[2] Collier, A. J., The Arkansas Coal Field. U. S. Geol. Survey, Bulletin 326, 1907.

In the Great Plains of Montana, Wyoming, and the Dakotas, coal seams of late Cretaceous or basal Eocene age underlie enormous areas. The coal is generally a glistening black lignite which is relativly pure and burns well, but is objectionable chiefly because it contains much water. Some of the lignite seams of North Dakota are 6 to 10 meters thick and many of them are so well exposed along the sides of the valleys that they are easily mined without machinery. Altho considerable quantities of this lignite are used locally for fuel, there is but little systematic mining, and scarcely any of the product is, as yet, shipt more than a few miles.

Puget Sound District. In northwestern Washington, along the eastern side of Puget Sound, valuable coal deposits are mined from the Eocene rocks. More than 125 workable coal seams, a few of which reach a thickness of 20 meters, are distributed thru an enormous series of sandstone and shale beds 3000 to 4000 meters thick. The coal is partly lignite and partly semi-bituminous,—the latter variety prevailing, where the beds are considerably folded. Locally, near igneous intrusions, hard anthracite and even coke are found in small quantities. The Puget Sound coals provide the only domestic source of coke on the Pacific slope of the United States. In 1907 the total production of coal in this district exceeded 1800000 metric tons.

Other coals of Eocene age are mined in a small way in Oregon and California. In both states most of the coal districts are in the Coast Ranges.

Peat.

Altho peat is but little used in the United States today, there is a growing interest in its possibilities. Unquestionably there are enormous quantities of the material available for future use. Thousands of peat bogs are scattered over the glaciated portion of northern and eastern United States, and to these must be added the extensiv coastal and riparian swamps of the eastern and southern states. C. A. Davis estimates that the available quantity of dry peat in the United States is more than 11 billion metric tons.

Petroleum and Natural Gas.

The United States is now much the largest producer of petroleum and natural gas among the countries of the world. Since the two products are almost always found together and are doubtless related in origin, they will here be treated as one.

Distribution.

Geographic. The oil and gas fields of the United States are widely scattered (see map). In the East a large field includes portions of Pennsylvania, New York, Ohio, West Virginia, and Kentucky. There are others in Indiana, Illinois, Oklahoma and Kansas. Along the Gulf coast in Louisiana and Texas there are several small but wonderfully productiv oil fields. The westernmost of the leading oil districts is that of southern California. Colorado, Wyoming, Utah and Michigan all contain small oil and gas deposits. The fields in eastern United States,—the first to be discovered and used,—are much less productiv than formerly. Even the districts of the Gulf coast are now showing a tendency to decline. On the other hand many new fields have been discovered within the last decade and more may be expected. On this account the production of oil and gas in the United States as a whole is rapidly increasing.

Stratigraphic. Altho the stratigraphic range of oil and gas in this country is large, the products come from a comparativly few geologic systems. In the eastern interior, all of the supply comes from Paleozoic rocks,—chiefly Ordovician in Ohio, Devonian in New York, and Carboniferous in most of the other states. In the Rocky Mountains the Carboniferous and Cretaceous rocks furnish nearly all of the oil and

gas. Along the Gulf coast and in southern California the oil is found in beds of early to middle Tertiary age.

Typical oil and gas districts.

Eastern Interior Field. Oil was first discovered and has been longest used in western Pennsylvania and the surrounding districts of New York, Ohio, West Virginia, Kentucky, and Indiana. Since the opening of this field in 1859, enormous quantities of oil have been produced, and the flow of gas has given many towns and cities all the fuel they needed for several decades. The production of the field is now, however, decreasing, many wells having ceased to yield either oil or gas, while only a few new discoveries are being made from time to time.

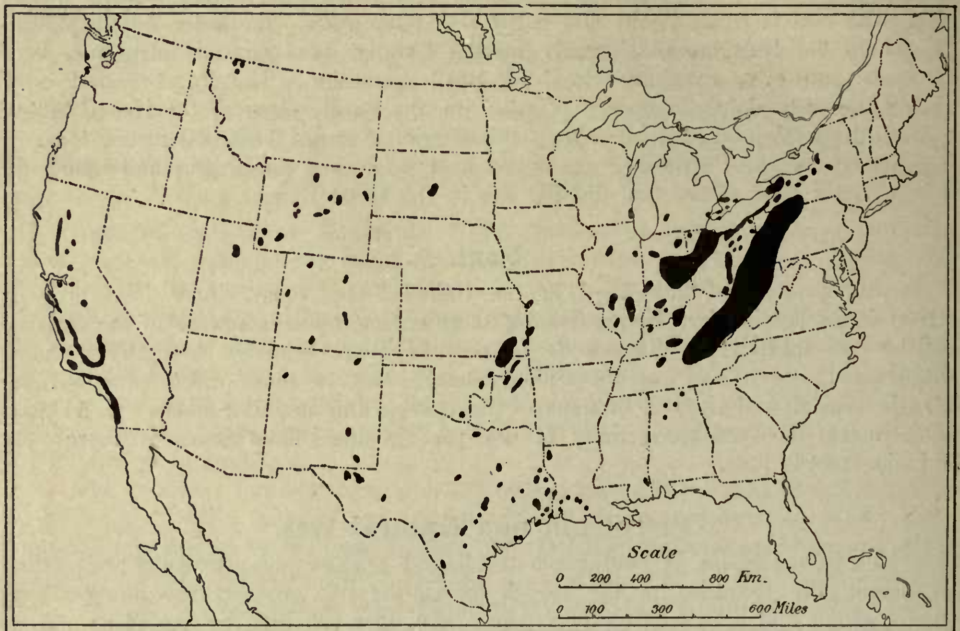

Fig. 76. Distribution of petroleum and natural gas fields in the United States. (After D. T. Day, U. S. Geol. Surv.)

The rocks of this district[1] are of Paleozoic age, and are either horizontal or gently undulating. The oil is contained in rocks of different ages in various parts of this large region. In Indiana and northwestern Ohio the porous Trenton limestone of Ordovician age is the principal oil reservoir. In southwestern New York, oil is obtained from the Devonian sandy shales. In southeastern Ohio and adjacent states much of the oil occupies Mississippian sandstones, but a little comes from the Pennsylvanian. The chief receptacles of the oil are the porous strata of sandstone or dolomite. The oils from limestone usually contain a notable quantity of sulphur, but those from sandstone generally do not. Most of the productiv oil wells are associated with low anticlinal folds which have permitted the concentration of oil along the crests of the arches beneath layers of impervious shale. Some of the eastern oil deposits, however, are in synclines.

The oil of the eastern interior field is generally of fine quality. It has a specific gravity of 40 to 50 B., and the residue after refinement is paraffin rather than asphalt.

[1] See reports of state geological surveys of Pennsylvania, Indiana, West Virginia and Ohio.

The gas associated with it contains 90% of methane (CH_4) and is nearly free from sulphur. It is valuable as an illuminant and as fuel. The oil from western Pennsylvania yields a particularly high percentage of gasoline and illuminating oils.

Other oil and gas deposits similar to those of the Ohio region have been found in southeastern Illinois[1], portions of Kansas[2], at Corsicana in Texas[3], and in several parts of Colorado.[4] In all of these regions the oils are light and yield a paraffin residue. In almost all cases the oil-bearing strata are sands imbedded in impervious shales,—the age of the strata varying among the different districts.

Southern California Field.[5] Altho oil and gas were discovered in California only a few years ago, that field has risen to be one of the most important in the United States. The wells, groupt in small isolated districts, are scattered over the

Fig. 77. Profile of oil-bearing Tertiary beds near Los Angeles, Cal. The oil sands are represented in black (after R. Arnold, U. S. Geol. Surv.).

southern portion of California,—part of them being found in the interior valley near Lake Tulare, and the rest along the southwestern slope of the Coast Range near the Pacific Ocean.

In this district the conditions are notably unlike those in eastern United States. The oil and gas have accumulated in porous sandy beds envelopt in shales of Eocene and Miocene age. All of the strata are moderately, and in some places closely, folded. In some districts it is evident that the oil is now concentrated in beds considerably above those in which it originated. Thus in the Coalinga district the oil is found at many horizons from Eocene to Miocene, but Arnold finds evidence that nearly all of it was derived from the Tejon (Eocene) bituminous shale.

Unlike that of the eastern districts, the oils in California are generally black liquids, having a large percentage of asphalt in the residue. In specific gravity these oils range from 12 B to 35 B, with an average of 25 B or less. For the manufacture of illuminants such oils are of comparativly little value, inasmuch as the more volatil constituents are chiefly aromatic oils rather than benzines and naphthas. The crude oil is extensivly used for fuel, however, by railroads, steamships, and manufacturing establishments, and lately for road dressing. That part of the product which is refined yields a large quantity of asphalt each year. The gas, which is usually associated

[1] Blatchley, W. S., Petroleum Industry of Southeastern Illinois. Illinois State Geol. Survey, Bull. 2, 1906.

[2] Independence, Kans., folio (No. 159). Geol. Atlas U. S., U. S. Geol. Survey, 1908.

[3] Fenneman, N. M., Oil Fields of the Texas-Louisiana Gulf Coastal Plain. U. S. Geol. Survey, Bull. 282, 1906.

[4] Fenneman, N. M., Geology of the Boulder District, Colorado. U. S. Geol. Survey, Bull. 265, 1905.

[5] Arnold, Ralph, Contributions to Economic Geology. U. S. Geol. Survey, Bull. 285, 1906, pp. 357—361.

Arnold, Ralph, and Anderson, R., Preliminary Report on the Santa Maria Oil District, California. U. S. Geol. Survey, Bull. 317, 1907; Geology and Oil Resources of the Santa Maria Oil District, California. U. S. Geol. Survey, Bull. 322, 1907; Geology and Oil Resources of the Coalinga District, California. U. S. Geol. Survey, Bull. 398, 1910.

Arnold, Ralph, and Johnson, H. R., Preliminary Report on McKittrick-Sunset Oil Region, California. U. S. Geol. Survey, Bull. 406, 1910.

with the oil wells and sometimes in destructiv quantities, cntains soulphurous components such as hydrogen sulphide and sulphur dioxide, so that much of it is unsuitable for fuel purposes.

As in most districts, the rate of flow of oil varies among the individual wells. Some give but a few hundred liters per day, while a few wells have spouted forth more than 300000 liters a day continually for months. The average production among good wells is probably 30000 to 50000 liters per day. As in other districts, here also, the flow of any individual well soon passes its maximum and thereafter slowly declines until, after some years, it becomes necessary to pump the oil to the surface. It is estimated that there is enough oil in the several districts already known in California to last more than 200 years at the present rate of consumption. The rate of consumption, however, is now rapidly increasing.

The Texas-Louisiana Field.[1] In western Louisiana and eastern Texas, rich oil and gas fields have been found in several localities. Among the best known of the individual districts are the Corsicana, Beaumont, and Spindletop fields. All of these fields derive their oil and gas from the horizontal or gently inclined Miocene, Eocene or Cretaceous sediments of the Gulf Coastal Plain. Since the formations are not uniform there is, however, a considerable variety of conditions and of production among the different fields.

It has been said above that the Corsicana district yields oil comparable to that of Illinois and the eastern interior fields. Except for the geologic age of the oil these two districts are much alike.

One of the smallest but perhaps the most remarkable of the southern oil fields is that of Spindletop in southwestern Louisiana. There oil was discovered by drilling into the top of a little knoll rising out of the coastal marsh near the shore of the Gulf of Mexico. The knoll proved to be structurally a dome, the underlying beds having been bulged up with dips of 10° to 15° on all sides. The oil-bearing stratum is a porous dolomite which is found to be thickest in the center of the dome, but thins away rapidly on all sides. Borings which have penetrated far below the dolomite have past thru as much as 90 meters of solid rock salt. The origin of such domes is not yet known. A. C. Veatch suggests that they may have been pusht up by local igneous intrusions from below, but G. W. Harris, noting the absence of all igneous rocks in that region, ascribes the domes to the lifting force produced by the crystallization of bodies of salt beneath the surface, the salt being introduced by the rise of salt-bearing solutions. Many similar domes without oil have been found in the same state and in Texas.

The Spindletop oil is associated with sulphur, which is found crystallized in the dolomite and is brought to the surface by springs. The accompanying gas contains a large percentage of hydrogen sulphide and has caused many deaths among the workingmen of the district.

Solid Hydrocarbons or Bitumens.

Varieties and modes of occurrence. Various bituminous products are found in the United States in the form of viscous tar-like materials and hard brittle bitumens. Several different varieties of the latter are distinguisht,—as gilsonite, grahamite, uintite, and ozokerite. Most of these hard bitumens are glistening black materials which break

[1] Hayes, C. W., and Kennedy, William, Oil Fields of the Texas-Louisiana Gulf Coastal Plain. U. S. Geol. Survey, Bull. 212, 1903.

Fenneman, N. M., Oil Fields of the Texas-Louisiana Gulf Coastal Plain. U. S. Geol. Survey, Bull. 282, 1906.

Harris, G. D., Oil and Gas in Louisiana. U. S. Geol. Survey, Bull. 429, 1910.

readily with a conchoidal fracture. They vary somewhat in composition and doubtless they intergrade with one another. Ozokerite contains a large proportion of paraffin, but the rest are more closely related to asphalt.

The soft viscous bitumens are found almost entirely in porous sandstone or dolomite, the rocks being saturated with the pasty tar-like matter. The hard bitumens generally occur in veins from a few centimeters to a meter or more in width, traversing the Cretaceous and Tertiary rocks,—chiefly in the western part of the United States. With the exception of a few small pools in southern California, no free asphalt analogous to the famous asphalt lake of Trinidad has been found in the United States. Large quantities are produced artificially, however, in refining the heavy crude petroleum of California.

The exact origin of the bitumens is still a matter of controversy, but growing evidence seems to indicate that they are the residues from the natural distillation of petroleum where the strata containing the latter are exposed at the surface. It is significant that such products are rare in the districts which yield the light paraffin oils, but are much more common where the oils are asphaltic in composition.

The total production of these hydrocarbons amounted to about 207000 metric tons in 1909, but of this more than one-half is artificially made from crude oil in California and Texas. About one third consisted of bitumen-saturated rock and gilsonite.

Distribution.

Geographic. Bituminous sandstones and limestones are known in California, Kentucky, and Oklahoma, and less commonly in Arkansas and Georgia. The chief deposits of hard bitumens are situated in Utah but there are some in Oklahoma.

Stratigraphic. The solid hydrocarbons have much the same geological distribution as the oils from which they are believed to have originated. Inasmuch as they could not be produced by the paraffin oils of the East, most of these bitumens are now found in the same Cretaceous and Tertiary rocks which yield the heavier oils in the western states. In southern Oklahoma[1], however, the asphaltic deposits are associated with sandstone and limestone of Paleozoic age.

C. Constructional Materials.

Stone.

General. The stones which are produced in largest quantities in the United States belong to the usual varieties,—granite, marble, sandstone, limestone and slate. The granite and marble are used largely for ornamental purposes, interior decoration, and for the more expensiv public buildings. Sandstone and especially limestone are used in much greater quantity for less pretentious buildings, foundations, bridge work and many other purposes. Slate is used in large quantities almost solely for covering roofs.

The following table shows the relativ values[2] of the different kinds of stone produced in the United States in 1909:

Slate, chiefly for roofing . . .	5 441 418	dollars
Granite	19 581 597	„
Trap rock	5 133 842	„
Sandstone	8 010 454	„
Marble	6 548 905	„
Limestone	32 070 401	„

[1] Taff, J. A., Tishomingo, Okla., folio (No. 98). Geol. Atlas U. S., U. S. Geol. Survey, 1903.

[2] Quantities cannot be given in this table because so many different units of measurement are in use.

Fig. 78. Distribution of slate, marble and granite in the United States. For slate and marble the location of quarries is shown. For the granite and similar crystalline rocks the general areas of exposure are represented.

Distribution. Supplies of stone are found in almost all parts of the United States, but are particularly deficient in the Coastal Plain and in the Great Plains of the western interior. Much the most important stone producing district comprises the eastern highlands and adjacent edge of the interior plains. Almost all of the slate, marble, and much of the granite comes from these eastern states,—particularly the Piedmont-New England province. In the central interior, between the Great Plains and the Appalachian Mountains, limestone and sandstone, used for building material and road construction, are the most important varieties of stone. Among the western states stone in not yet quarried in large quantities. This is due to lack of demand rather than to lack of available supplies. In the mountains there are of course vast quantities of rocks of many different kinds suitable for various constructional purposes. Today the stone output of the western states consists largely of granite and sandstone for building purposes, and limestone for metallurgical uses. The Pacific coast states and Colorado are now the largest producers, doubtless because they have the largest centers of population.

The individual varieties.

Granite. Under this term are included by the quarrymen not only true granite, but other coarse-grained igneous and metamorphic rocks such as gabbro, syenite, gneiss, and even porphyries. The total value of rocks of this character produced in the United States in 1909 exceeded 19000000 dollars. The leading states are Maine, Massachusetts, California and Vermont, in the order named. Vermont is celebrated for its fine gray and white granites used in making monuments and for interior decorations. It produces more than one-half of the granite used in the United States for such purposes. Wisconsin and Massachusetts rank second and third. Many of the Wisconsin granites are red and some of them porphyritic. Massachusetts leads in the production of rough building granite.

The granites used in the United States are of many different ages. Those of the eastern states are largely of late Paleozoic age, but include some which are pre-Cambrian. In California post-Jurassic granites yield nearly all of the supply. In Texas and Wisconsin all of the granites are of pre-Cambrian age, while in the Rocky Mountain region they are generally pre-Cambrian or post-Cretaceous.

Marble. The marble produced in the United States in 1909 was worth more than $6\,^1/_2$ million dollars. Almost all of it was quarried in the eastern states and more than half of the total came from Vermont, which is distinguisht for its fine monumental marbles. Several of the southern Appalachian states, particularly Tennessee and Georgia, are important producers of marble for building purposes and interior decoration. Large quantities of marble are available in different parts of the western mountain region but only a little has been used thus far. Washington is the most important marble producer among the western states but its total yield is less than $^1/_{100}$ of that of the entire country.

In the eastern states the marble is derived largely from the highly folded Cambrian and Ordovician formations, a little coming from the Algonkian system. In the western states Carboniferous and pre-Cambrian marbles are of chief importance.

Sandstone. Most of the sandstone quarried in the United States is used for building purposes. The total production of the country in 1909 was valued at over 8000000 dollars. Of the total amount Pennsylvania, New York, and Ohio produced more than 70 percent, but small quantities were quarried in many other states scattered thruout the country.

The sandstones used in the United States are of many and various ages. Some are white, some yellow, and some red or brown. Some are comparativly soft, while others are very hard and quartzitic. In Ohio and Pennsylvania the Carboniferous system

is the chief source of sandstone. In New York the Devonian strata yield the largest quantities. In Connecticut and New Jersey the Triassic brown sandstones have become famous among the eastern cities for the building of dwelling-houses. In northern Michigan similar brown sandstones of Cambrian or late Algonkian age are extensivly used in the north central states.

Limestone. Limestone serves many purposes. It finds its chief use in building and other constructional work such as the making of concrete, railroad beds, and bridge abutments. Large quantities are also used in the manufacture of lime and cement, for flux in smelting operations, and in the refining of sugar. Exclusiv of the limestone used in the manufacture of cement and lime, the production of the United States in 1909 was valued at more than 32000000 dollars, or much more than that of any other kind of stone. Pennsylvania, Illinois, and Ohio furnisht the largest quantities, more than 3000000 dollars worth having been quarried in each. All of the other central and eastern states, however, yield important quantities of limestone. In the West the production is much smaller,—Colorado and Utah being the leading states in that respect. The limestone there quarried is used chiefly for flux in smelting ores and in the process of refining beet-sugar. In the central states more limestone is used for road ballast, the manufacture of concrete, and other purposes requiring crusht stone, than in any other manner.

While supplies of limestone are obtained in the United States from rocks of almost all ages, much the largest quantity is derived from the Paleozoic systems. In the eastern states Ordovician, Silurian, and Mississippian strata furnish most of the supply. In the west the Carboniferous beds are the most important source of limestone, but Ordovician and other systems yield considerable quantities.

Slate. The slate quarried in the United States in 1909 was worth more than 5000000 dollars. About 95 percent of the total came from Pennsylvania and Vermont. Outside of the Appalachian states there are large deposits of slate in California, Oregon, Nevada and Washington, but even in California the production is still very small.

Slate is used in the United States largely for roofing, but to a small extent for various other purposes, such as the making of school blackboards and slates, and for electrical switchboards.

The great slate deposits of the eastern states are largely of Ordovician age, but in some localities the beds belong to the Cambrian, pre-Cambrian or Devonian systems. In California the slates are largely Jurassic or Carboniferous in age.

Cement.

Varieties. The use of cement in the United States has increast with extraordinary rapidity since 1896. Three varieties are now manufactured there. More than 90 percent of the total is Portland cement, the rest being so-called "natural cement" and puzzuolan. Before 1898 the natural cement was manufactured in largest quantity, but the increast production of the Portland variety, causing a decline in the manufacture of natural cement, has resulted in a complete revolution in the industry.

The Portland cement is made of limestone or marl, combined with the proper proportions of shale or clay, and subjected to a mixing and drying process. A small quantity is made from furnace slag mixt with limestone. In 1909 the value of the Portland cement product was more than 52000000 dollars and the rate of increase has since been very rapid.

The natural cements are made from argillaceous limestone, in which there happens to be the required ratio between calcium carbonate and clay. A decline in the production of this variety is doubtless due to the difficulty of finding limestones with exactly the right composition, whereas it is comparativly easy to mix pure lime-

stone and shale artificially in any proportions desired. In 1909 the natural cement produced was worth less than 700000 dollars and the manufacture of it is still decreasing.

Puzzuolan, made from a mixture of furnace slag and hydrated lime, is manufactured on a small scale in several places in eastern United States, chiefly near the large steel furnaces. Enormous quantities of volcanic ash in the western mountains could be utilized, as in Italy, but thus far are neglected. The production of puzzuolan in United States in 1909 was valued at 100000 dollars.

Hydraulic cement is no longer manufactured in the United States in important quantities.

Distribution. Cement, like many other products of low value, is manufactured chiefly near its markets. It thus happens that nearly all that material produced in the United States comes from the vicinity of the large cities in the East.

More than half of the total is produced by a district in eastern Pennsylvania and adjacent portions of New Jersey and New York. In this region the Ordovician rocks generally furnish the limestone, while the argillaceous material is taken either from adjacent shale formations or from Pleistocene clay. On account of the scarcity of unaltered limestone and shale in New England, but little cement is produced there.

Considerable quantities of cement are manufactured in other eastern states, such as Michigan, Indiana, and those along the Appalachian Mountains. The limestones there utilized are of various ages, generally Carboniferous in Michigan and Kansas, and Mississippian in Tennessee.

In other parts of the country, especially in the western mountains, there are vast deposits of materials which could be made into cement. These are utilized, however, in but few places, and the markets are local. The states of chief importance in this respect are California, Utah, Colorado, and Washington. This preeminence is probably due more to the fact that they contain the larger centers of population, than to any special richness in cement materials.

Clays.

In the United States the brick, tile, pottery, and other products manufactured from clay are valued at more than 150000000 dollars per year. The quantity and value of the raw clay cannot be ascertained, because most of it is sold only in the manufactured condition.

The clays themselves are of many kinds and of different ages. The marine and estuarine deposits yield some of the most valuable clays. In northeastern New Jersey, Cretaceous clays of this sort are used in the manufacture of pottery, as well as brick and other products; and the early Eocene beds of the Mississippi embayment are adapted to the same uses. The Quaternary marine and lacustrine clays along the Hudson and St. Lawrence valleys, are similarly valuable. The lacustrine clays, which are distributed chiefly over northeastern United States within the glaciated region, are widely used for making brick.

Fluviatil clays are the only available deposits in many portions of central, southern, and southeastern United States. Such clays are present in large quantities but are usually too impure for the manufacture of any of the finer clay products. The same is true of the purely glacial clays of the northern and northeastern states. Residual clays, derived from the decay of the rocks in situ, are of wide distribution outside of the glaciated portion of the United States. Generally they are suitable only for the manufacture of brick and tile, but locally some of them are adapted to other uses. The soils from certain purer limestones are sufficiently free from iron to be used in the manufacture of pottery.

The finest clays and the most valuable are the kaolinic deposits which originate from the decay of feldspathic rocks. Such deposits are generally small, and the majority

of those known lie in the Piedmont region in situations where pegmatite dikes rich in feldspar have decomposed. The best known kaolin mines are in North Carolina and southeastern Pennsylvania.[1]

Altho slate is too hard for the purpose, the softer varieties of shale are extensivly utilized as clay. The shales beneath the coal seams in the Pennsylvanian rocks of eastern United States, furnish material for the manufacture of fire brick, furnace linings, and other special products, the annual value of which is large. In addition, soft shales are widely used in the manufacture of cement (see page 242) and locally are pulverized and baked into brick.

Gypsum.

In the production of crude gypsum the United States outrankt in 1909 all other nations, including France, which was until recently the leader. In that year the production amounted to 2040000 metric tons, valued at more than 4000000 dollars. Most of it is manufactured into plaster, which is graded and adapted for various uses. A small but increasing quantity is utilized as a fertilizer for alkaline soils.

Deposits of gypsum have been found in many parts of the United States, both eastern, central, and western. The largest known quantities exist in the western interior states, such as Oklahoma, Kansas, Wyoming, South Dakota, and Colorado. The actual production, however, now comes chiefly from the eastern states, not because the deposits of gypsum there are larger than elsewhere, but because they are near the markets afforded by the large eastern cities. On this account the leading states in the production of gypsum are Michigan, New York, and Iowa, with Oklahoma and several other western states as important producers.

The gypsum mined in the United States comes from rocks of many ages, from early Paleozoic to Quaternary. The great gypsum deposits of the western interior region form part of the Permian and Triassic red beds. Some of these gypsum beds reach a thickness of more than 20 meters, and layers 3 to 5 meters thick are rather common. The most valuable deposits of eastern United States are those in the Cayugan (Salina) series of the Silurian system in western New York and adjacent parts of Ohio. In Michigan, beds of gypsum are found near the top of the Mississippian system, and in Virginia likewise the small but important deposits near Holston river are associated with the Mississippian limestone. The age of the Iowa beds is not known, but they are generally thought to be Permian. On the Pacific coast, notably in California, numerous small deposits of gypsum are associated with Eocene strata; and in Texas and Louisiana the Oligocene system is the containing formation. Small deposits in Florida are associated with the Quaternary strata and there are others of an even more recent age in Utah and particularly Nevada, where gypsum lines the basins once occupied by saline lakes. In Otero County, New Mexico, pure gypsum sand, gathered into dunes by the wind, is used in the manufacture of plaster.

Sand and Gravel.

Both of these materials are widely but irregularly distributed over the United States. There are but few large districts without adequate supplies. In the northeastern states the chief sources of sand and gravel are glacial kames and outwash deposits; elsewhere the supply comes from beaches of the oceans and large lakes, river banks and terraces, unconsolidated marine strata chiefly of Cretaceous or Cenozoic age, and in some localities from ancient formations such as the St. Peter and Sylvania sandstones of north central United States.

The sand and gravel excavated in the United States is used chiefly in the making of concrete and mortar, as road ballast and to a small extent in the making of glass

and in other manufactures. As with other low grade materials, the cost of transportation decrees that only the deposits located near cities and other centers of population shall be extensivly used. At present much the largest part of the production comes from the northeastern states. The total product in 1909 was about 54100000 metric tons, valued at more than 18000000 dollars.

D. Fertilizers.

Phosphate Rock.

In the production of rock phosphate the United States nearly equals all other nations combined. In 1901 its total output was more than 2100000 metric tons. The crude material contains 40 to 80 percent of tricalcium phosphate, and occurs either as an

Fig. 79. Known deposits of gypsum, phosphate rock and rock salt, in the United States. (In California, sea-brines are included.)

original sediment associated generally with limestone, or as a residual alteration product resting upon limestone. Phosphatic breccia and pebble deposits constitute other modes of occurrence. In some localities small quantities of apatite and wavellite in veins among the crystalline rocks are mined as sources of phosphorus.

Altho there are important phosphatic beds in Tennessee and South Carolina, Florida produced in 1909 about 77 percent of the total output of the United States. The material there forms irregular residual accumulations resting upon Tertiary limestone. Detrital phosphatic gravel derived from the original deposits is also workt.

The greatest reserve quantities of phosphate rock which have been thus far discovered in the United States constitute a part of the Permo-Carboniferous limestone of southeastern Idaho and adjacent portions of Utah and Wyoming, but most of the outcrops are at present too far from markets to be profitably mined. The deposits consist of black phosphorite (oolitic lime-phosphate rock) in beds which average 1 to 2 meters in thickness, and some single beds seem to be continuous over many thousand square miles. It is

safe to say that in this field there exists far more than ten billion tons of phosphate rock containing more than 70 percent of tricalcium phosphate. The quantities of low

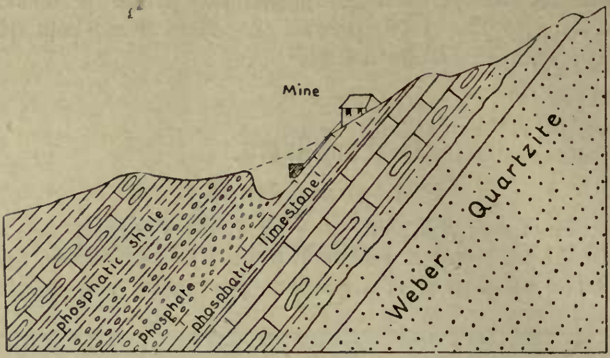

Fig. 80. Diagram showing the occurence of phosphate rock in the Carboniferous strata of southeast Idaho.

grade phosphate rock (30—70 percent) are much greater. As yet the areal extent of the western phosphate district has not been ascertained closely.

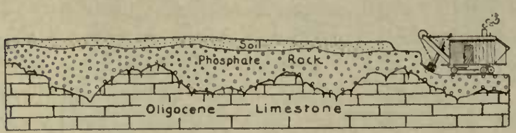

Fig. 81. Diagrammatic profile of a residual deposit of phosphate rock in Florida.

E. Miscellaneous Economic Deposits.

Many other non-metallic mineral products are found in various portions of the United States, and of these some are of considerable importance. Space will not permit, however, more than a cursory mention of these minor deposits.

Abrasiv Materials.

The abrasivs manufactured in the United States are made from various materials. The total output in 1909 was valued at 1330000 dollars, and came largely from the Piedmont district of eastern United States. Grindstones and whetstones, generally made of hard sandstone or quartz schist, are produced in several of the eastern and central states. The novaculite of southern Arkansas is prized for making fine sharpening stones. It is merely an extremely fine and somewhat argillaceous quartzite.

Emery, which is commonly a mixture of corundum, spinel and other minerals, is found in small quantities in the metamorphic terranes of eastern New York and Massachusetts. The production of this material has decreast by 400 percent since 1900, probably because carborundum and other artificial abrasivs are in greater demand. Quartz and feldspar, for use as abrasivs, are mined from pegmatite dikes in the Piedmont states and in Wisconsin; and from the schistose rocks of New York, Pennsylvania, and North Carolina, quantities of garnet are mined and used in the making of polishing papers. Tripoli and infusorial earth, also used as polishing powders, are found chiefly in the Tertiary rocks. Missouri and California appear to contain the largest known deposits but Illinois and the coastal plain of Virginia are also producers. In Nebraska a bed of fine volcanic dust occurs in Miocene strata almost thruout the state; it is excavated for use as an abrasiv. There are large deposits of similar volcanic ash in other western states, but they are not yet utilized.

Graphite.

The graphite deposits of the United States are far from able to supply the domestic demand. In this country the material is found in lenticular beds, interlaminated with schists and gneisses, or as graphitic quartzite. Most of the supply now comes from the pre-Cambrian rocks of the Piedmont region and New England, but deposits are known in the western mountains and may prove to be valuable in the future. The production of graphite in the United States, seems to be decreasing. In 1909 the amount produced was worth about 345000 dollars; more than one-third of it by weight was crystalline graphite.

Asbestos.

The mining of asbestos had been on the decline in the United States for some years, but revived notably in 1909. In that year 2800 metric tons were produced. In Georgia, the chief producing state, the asbestos is of the amphibole variety, which is not considered as good as chrysotile asbestos. Other deposits are known in Texas, Wyoming, Idaho, Virginia, Arizona, and California, but they are as yet but little utilized. The asbestos occurs chiefly as veins or lenses in basic schists or in serpentine and peridotite.

Talc and Steatite.

These minerals find a variety of uses in the arts and manufactures. In 1907 the value of the product was more than 118000 metric tons. The minerals occur generally in sheets interleaved with gneiss, schist or marble but in some instances as alteration products of ultra-basic igneous rocks; the most important deposits now known are in the pre-Silurian terranes of the Piedmont and New England states. Virginia produces nearly one-half of the total. Other deposits are known in the West, but they are generally not mined.

Salt.

In 1909 the United States produced nearly all the salt consumed in the country, or about 3800000 metric tons. The most important district commercially is in northeastern United States, particularly in the states New York, Ohio, Michigan (see map on p. 245). In that region the salt is generally brought to the surface as brine, derived from the thick beds of rock-salt in the Salina formation of Silurian age. In one or two places rock salt is mined from shafts.

In Kansas the Permian red beds yield large quantities of salt, also taken out in the form of brine. In Louisiana there are peculiar dome-shaped bodies of crystalline salt in the sediments of the coastal plain (see under Oil). Some of these deposits are mined from shafts. Salt as well as soda and borax occurs in the form of surface crusts in the bottoms of many extinct lakes in the desert portion of Utah, Nevada and California, but as yet they are not much used.

Sulfur.

Until recently the United States has not been an important producer of sulfur, but its output has been rapidly increasing until in 1909 it exceeded 243000 metric tons and some sulfur was exported. Most of the supply comes from the peculiar domes of salt-bearing dolomite in southern Louisiana. Smaller quantities are found in the deposits of hot springs in Wyoming and in association with young volcanic rocks in Nevada and Utah.

Pyrite.

Vast deposits of pyrite occur in various parts of the United States, especially in the ore bodies of the more valuable metals; but little use is made of them. In 1909 248000 metric tons of pyrite were mined chiefly for the manufacture of sulfuric acid.

Virginia yields more than one-half of the total supply, but California, New York, and the southern Appalachian states are also important in this respect. The pyritic bodies thus utilized are generally lenses, associated with schists in much the same way as the magnetite deposits already described.

Magnesite.

California is the only state in the Union that supplies noteworthy quantities of magnesite. Its production in 1909 amounted to 8595 metric tons. Many scattered deposits of the mineral are found in the form of veins traversing serpentine in southern California, but of these only a few are mined. Small bodies have been found in several of the eastern states but are not utilized. The product is used in the manufacture of paper.

Barite.

About 52600 metric tons of barite were produced in the United States in 1907. Most of this came from southern Missouri and the central and southern Appalachian states. In both of these localities it is generally found in the form of crystals and irregular bodies imbedded in residual clays derived from Paleozoic limestone. The mineral is common as a constituent of veins in some of the metalliferous deposits of the western mountains, but little if any effort is made to save it in the course of mining.

Borates.

Altho small deposits of borates have been found in playas in Nevada and Arizona, nearly all of the deposits now utilized are situated in the desert of southeastern California. They consist of colemanite in the form of chemically precipitated layers in Tertiary and Quaternary lake-beds. The same mineral occurs in small veins in early Tertiary rocks in the same region.

The annual production usually exceeds 45000 metric tons.

Fluorspar.

The chief center of fluorspar production in the United States is a district near the mouth of the Ohio river in Kentucky and southern Illinois, where large veins of the mineral intersect the faulted Mississippian limestone. Smaller deposits are known in Colorado and Tennessee. In the western states small quantities are saved as a by-product in some of the metal mines, where the fluorspar is often associated with galenite. The production for 1909 was more than 50000 metric tons.

Mica.

Altho small bodies of mica are widely distributed thruout the United States, most of the supply comes from the Piedmont belt of eastern United States, with important quantities from South Dakota and Colorado. The mica occurs in pegmatite veins, generally in ancient metamorphic rocks. Muscovite and phlogopite are the varieties of mica which are generally mined in this country. The product is marketed in the form of sheets and is also pulverized for lubricating purposes. The total quantity in 1909 was about 4500 metric tons, of which one fifth was sheet mica.

Gems and Precious Stones.

The United States is not distinguisht for its gems, altho some of the less valuable stones are found there in important quantities, and nearly all the common gems occur sparingly. Rose quartz, petrified wood, agate, jasper, and other forms of quartz are produced in comparativ abundance in both the eastern and western mountains. Considerable quantities of amazon-stone are found in Colorado. According to

value, the sapphires from placer mines and from basic dikes in central Montana constitute half of the total production; variously colored tourmalines, chiefly from California, Colorado and New England, rank next (about $^1/_6$); chrysoprase from Arizona, about $^1/_{10}$; californite, a jade-like variety of vesuvianite from northern California, more than $^1/_{20}$; and turquoise from the southwestern desert states about $^1/_{20}$. A few diamonds have been found from time to time scattered in the glacial drift over the northern and Pacific coast states, but only within the last few years have they been discovered in situ in Pike County, Arkansas. There several hundred stones have been taken from the decayed outcrops of two pipe-like intrusions of peridotite. The value of this discovery is yet doubtful.

The total value of gems and precious stones produced in the United States was 534000 dollars in 1909, and a comparison of the figures for the last few decades shows a rapid increase in the production of most of the varieties.

VI. Summary of Literature.

The number of papers publisht on the regional geology of the United States each year has become so large, and the total volume of the literature of the subject has grown to be so great, that it will be possible here merely to enumerate the principal groups of publications on the subject, and to list a few of the more important general works.[1]

Publications by National and State Governments.

United States Geological Survey.

1. Monographs. A series of quarto volumes which include descriptions of many districts.
2. Annual Reports. Volumes I-XXII contain many papers on regional geology as well as theoretical, technical and administrativ reports.
3. Professional Papers. Brochures containing scientific papers like those which before 1902 were publisht in the annual reports.
4. Bulletins. Smaller reports of a preliminary or transient nature, many of them for popular use.
5. Geologic atlas. A series of folios describing selected rectangular districts. They contain geologic, topographic, and other maps with explanatory text and profiles.
6. Water Supply and Irrigation Papers. Small statistical and technical reports. Some of them contain data on stratigraphy and regional geology.
7. Mineral Resources of the United States. Statistical summary of economic products and the progress of mining. An annual publication.

Special National Surveys.

A series of quarto reports on early geological explorations of western United States. Much classic work of a high order. Gilbert, Hague, Emmons, Meek, Marsh, Cope, Powell, Dutton, King and Zirkel were among those engaged in this work.

1. U. S. Geographic and geologic explorations and surveys West of the 100th Meridian. (Wheeler).
2. U. S. Geological and Geographical Survey of the Territories. (Hayden).
3. U. S. Geological Survey of the 40th Parallel. (King).
4. U. S. Geographical and Geological Survey of the Rocky Mountain Region. (Powell).
5. Special expeditions. Reports in the form of War Dept. reports or of Documents of the Senate and House of Representatives. Largely exploratory but many of them important.

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[1] For detailed references to papers on the areal geology of the United States, see the annual bibliographic bulletins publisht by the United States Geological Survey (Nos. 127, 177, 188—189, 301, 379, 409, 444 and 495, up to 1910 inclusiv).

State Geological Surveys.

All of the 46 states have conducted geological surveys and publisht reports thereon, except Nevada, Utah, Montana, Oregon and Idaho. Most of them have been primarily economic and statistical in their purpose. Those which have contributed most to general geologic knowledge are as follows:

1. New York. A great series of quarto reports, bulletins, and memoirs begun in 1837. The earlier work of this Survey has become classic in American geology. One series of eight volumes deals with Paleozoic fossils alone. Hall, Vanuxem, Clarke and H. S. Williams were among the writers.
2. Pennsylvania. A long series of small reports by H. D. Rogers and many others chiefly on the coal-bearing strata of the state. Buried in the mass is much valuable data on structure and stratigraphy.
3. Ohio. Reports of Newberry, Orton, and others. Many are paleontological.
4. Indiana. Reports of Hall, Blatchley, and others.
5. Illinois. Reports of Worthen, Bain, and others. The older volumes are largely paleontological but recent reports are chiefly economic.
6. Wisconsin. The 4-volume general report of Chamberlin (1871—1877) is one of the best state reports ever written and remains a standard work today. Later bulletins deal with special subjects.
7. Maryland. Several monographic reports on coal, Eocene and Miocene fossils, and other subjects. The rest contain descriptions of individual counties.
8. New Jersey. Reports by Cook, Kümmel, and others. Four are paleontological. The rest deal with stratigraphy and mineral resources.
9. Minnesota. Seven large quarto volumes on geology, paleontology, etc. N. H. Winchell, U. S. Grant, and E. O. Ulrich were the chief contributors.

Publications by Private Institutions and Societies.

Academies of Sciences. (Proceedings, Transactions, etc.)

Academies of Sciences have been establisht in most of the larger cities of the United States, and their publications contain much geological information, chiefly of a local nature. The majority of papers deal rather with paleontology than with other phases of geological study. The Academies of Science whose publications are of chief importance are as follows:

National Academy of Science, Washington, D. C.
Academy of Natural Science, Philadelphia.
Chicago Academy of Sciences.
Academy of Science of St. Louis.
New York Academy of Sciences.

Museums (Reports, Proceedings, Memoirs, etc.)

The larger museums of the United States publish reports on investigations, some of which are geologic; of these the majority deal with paleontology and especially with the vertebrate branch of that subject.

1. New York State Museum. A long series of annual reports (begun in 1843) and bulletins (begun in 1893), containing many short papers on paleontology and some on geology. There are in addition large memoirs or monographic reports, of which 11 had been publisht up to 1907. Several of these are paleontological.
2. New York State Cabinet of Natural History. A series of reports among which are many papers chiefly on invertebrate fossils from the Paleozoic rocks of New York state.
3. Carnegie Museum, Pittsburg. The publications dealing with geology and paleontology are devoted chiefly to vertebrate fossils from the western states.
4. American Museum of Natural History. Bulletins and memoirs containing many papers on invertebrate fossils and some on vertebrate fossils and general geology.
5. Smithsonian Institution, Washington, D. C. The Annual Reports, Contributions to Knowledge, and Miscellaneous Collections, contain scattered papers on paleontology and mineralogy, and more rarely on geology.

6. U. S. National Museum. The Proceedings contain numerous short papers chiefly on paleontology.
7. The Museum of Comparative Zoology of Harvard College. Among the publications of that institution is a geological series containing excellent papers on a wide range of geologic subjects.

Scientific Societies.

1. Geological Society of America. (1890—present.) The publications of this society are issued at frequent intervals as separate brochures. The majority of the papers deal with theoretical questions in geology, and with areal studies.
2. Boston Society of Natural History.
3. Buffalo Society of Natural Sciences. Papers on both geology and paleontology, chiefly in the vicinity of Buffalo, N. Y.
4. Cincinnati Society of Natural History. Many papers on the invertebrate fossils of the early Paleozoic formations of Ohio and adjacent states.
5. American Geographical Society (New York). The proceedings and bulletins contain many papers on the physiographic aspect of regional geology.

Universities and Colleges.

1. University of California, Department of Geology. A series of bulletins on geological investigations by members and students of the department.
2. School of Mines Quarterly. A magazine issued by the technological departments of Columbia University, New York City. It contains many papers on geology, chiefly the economic phases of the subject.

Periodicals.

1. Journal of Geology. (1893—present.) The papers are exclusivly geological and paleontological, and contain the results of regional investigations. Eight issues each year.
2. Economic Geology. (1906—present.) A monthly magazine dealing with geology as applied to mining and the utilization of economic products. Many descriptions of mineral districts.
3. American Geologist. (1888—1906.) A monthly magazine in which were publisht articles on many subjects covering the entire range of geology. It has since been consolidated with Economic Geology.
4. Science. A weekly magazine in whose pages there are many brief articles, abstracts and reviews on geological topics.
5. American Journal of Science. (1818—present.) A monthly magazine devoted to physics, chemistry, biology, and geology. The geological papers are largely of a theoretical nature, but not a few are regional.
6. National Geographic Magazine. (1888—present.) The first few volumes contain important papers on physiographic and regional geology; later volumes are almost wholly geographical in subject matter.

Books.

1. Chamberlin and Salisbury, Geology. 3 volumes, 1904—6. This is the standard text-book of North American geology at the present time. The 2nd and 3rd volumes, on geologic history and stratigraphy, give much information on regional geology.
2. Dana, J. D., Manual of Geology. For many years the standard compendium of American geology. There are four editions.
3. Kemp, J. F., Ore Deposits of the United States and Canada. Contains brief descriptions of the more important mining districts of the regions named.
4. Ries, H., Economic Geology of the United States, 1910.
5. Lakes, A., Geology of western Ore Deposits. 1905.
6. Tarr, R. S., Economic Geology of the United States. 1896.
7. Osborn, H. F., Age of Mammals, 1910.

8. Powell, Davis, Willis, and others. Physiography of the United States. A group of short monographs on important physiographic districts and on the United States as a whole.
9. Russell, I. C. Volcanoes of North America.
Lakes of North America.
Glaciers of North America.
Descriptions and historical summaries of the more important volcanoes, lakes, and glaciers of North America.

VII. Table of Names of Formations

by K. Stamm.

Table of Contents.

The Philippine Islands

by

Warren D. Smith.

With a chapter on the Lithology

by

J. P. Iddings.

I. Morphological Summary.

The Philippine Archipelago forms a link in that great eastern chain of islands fringing the Asiatic continent, and a part of the Pacific Arc, some three or four hundred miles east of the mainland between the Japanese Islands and Formosa on the north, and Celebes and Borneo on the south.

The number of islands large and small is not yet definitely known, but the latest estimate of the Coast and Geodetic Survey places it approximately at three thousand. The total area is about 115,026 sq. mi., the total length of coast line is 11,511 mi. approx. The largest island is Luzon, with an area about equal to that of England; Mindanao is second; Leyte, Samar, Panay, Negros, Cebú, Palawan, and Mindoro composing a secondary group, each of about the size of the island of Crete; then a host of lesser ones ranging from those just mentioned on down to mere rocks standing up out of the sea.

The Philippines, with Formosa, Japan, Celebes, Borneo, New Guinea, in fact most of the islands of the Malay group are, in the opinion of writer, to be regarded as the rough, shattered loose ends, as it were, of the Asiatic Continent. They mark the border of the continental plateau, the high points of the crumpled edge of the land horst. This seems to be supported by the fact of the existence of very great deeps very close to and east of Japan and the Philippines found during the soundings of the Planet[1].

The main tectonic lines in general run north and south, but minor departures from this are to be seen in the lines running through the Islands of Palawan and Mindoro and that taking in the Sulu group, Zamboanga Peninsula and Cebú.

The writer's conception is that the various cordilleras represent the crests of a series of anticlines, but the existence of minor cross folding and perhaps faulting cause these to be interrupted. The synclinals, whose bottoms fall below sealevel, exist as narrow straits. These are common in the archipelago. The strait between Negros and Cebú marks such a synclinal. A similar trough, once occupied by water, exists between the Zambales range, western part of Luzon, and the eastern cordillera. This is now a long, flat plain, known as the great central plain of Luzon. The material

of this plain is made up largely of pyroclastic material to the south and marine sediments and piedmont deposits to the north. As is to be expected, the lines connecting the various active and extinct volcanoes correspond very closely to the crests of these anticlines.

II. Stratigraphy and Lithology.

A. Stratigraphy.

From the following tentative scheme of the stratigraphy (p. 3) it will be seen that we have no sedimentary formations known with certainty to be older than the Eocene. That there are any sediments older than Oligocene is not positively established. *Nummulites* were reported by Abella[2] and Richthofen[3]. In their type localities abundant orbitoidal forms have been collected but no *Nummulites*. It is not probable that the gneous complex of diorite, gabbro, etc. is very old. Just what place the crystalline

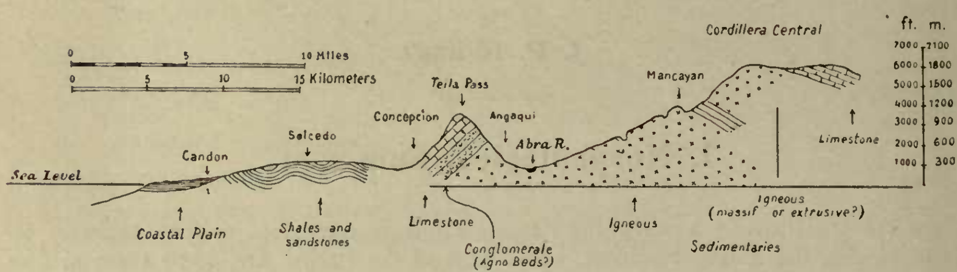

Fig. 1. Ideal section W.-E. west coast of northern Luzon at Candon to Cordillera Central (after Eveland).

schists occupy in the scale is a matter of conjecture entirely at the present time, for we have nothing but lithological criteria to depend upon. Von Drasche[4] put forth arguments for classifying the Agno beds as Paleozoic, but to the writer the evidence seems to be entirely inadequate. There was a time when most, if not all, crystalline schists and gneisses were put down as Archean, but there is no reason why we can not have Metamorphic rocks in the Tertiary; in fact, they are known. In the writer's opinion, age is merely incidental in the matter, dynamism is the chief factor.

Fig. 2. General section central Luzon.

The generalized sections in Figs. 1, 2, and 3, northern Luzon, central Luzon and Mindanao, will show graphically the succession in different parts of the Archipelago. The predominant rocks are by far the neovolcanics, andesites and basalts; next come the Tertiary sediments, for the most part Miocene; third, the intrusive rocks such as diorites, gabbros, diabase, quartz-diorites, granites and dacites etc. and fourth the metamorphics. Recently some Foraminifera and field notes were submitted by the writer to Prof. Douvillé of Paris, who has studied them, and on the basis of this has prepared the following table[5]:

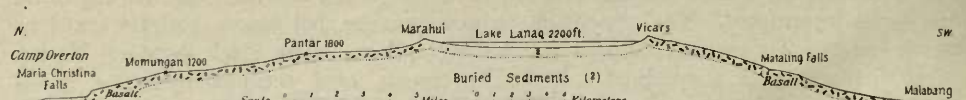

Fig. 3. Section from Camp Overton to Malabang, Mindanao.

Provisional Table of Philippine Stratigraphy.

Period.	Formation.	Type Locality.	Distribution.	Economic Deposit.	Characteristic Fossil.
Recent	Piedmont deposits including fluvial	Cagayan, Mind.	Throughout the Archipelago	Bench placers	
	Solfataras	Laguna Province	—	Kaolin and brick clays	
	Talus		Throughout the Archipelago	—	
	Spring deposits	Mountain Prov.	—	Gold, building sand	
	Coral reefs	Cebú	Along much of the Philippine Coast line	Building stone and lime	
	Littoral deposits	Sangley Point	—	Sand	
	Volcanic tuff	Vicinity of Manila	Southern Luzon, Ilocos Norte	„Guadalupe" stone for building	Leaves, probably belong to *Euphorbiaceae*
	Basalts and andesites flows	Mt. Arayat and Mt. Apó	—	Sulphur	
Unconformity	— — — — — — — —	— — — — — —	— — — — — — — —	— — — — — — — —	
Pleistocene and Pliocene	Raised coral reefs	Cebú west coast	Cebú, N. W. Luzon	—	
	Marls	Ilocos Norte	Samar, Agusan River	—	*Hindsia dijki* Mart.
	Eruptives	Mt. Mariveles	Mindanao	—	
Unconformity	— — — — — — — —	— — — — — —	— — — — — — — —	— — — — — — — —	
Miocene	Limestone (Upper)	Cebú	—	Burned for lime, very pure	Shells very similar to recent forms. Chiefly coral reefs
Unconformity	Andesite flows	Cebú	Cebú, Masbate, etc.	Gold, silver, manganese, lead	
Miocene	Limestone (Middle)	Cebú	Cebú, Central Luzon, S. W. Luzon, North and East Mindanao, Romblon	Romblon marble, Montalban limestone	*Lepidocyclina insulae-natalis* Chap., *Lithothamnium ramosissimum* Reuss.
	Sandstone	Batan Island	—	Oil in Tayabas and Cebú	*Cycloclypeus communis*, *Orbitolites*, etc.
	Shale	Batan Island	—	Coal deposits Cebú, Batan, Polillo, Masbate, Mindanao, Luzon, etc.	*Arca*, *Callianassa dijki* Mart., *Vicarya callosa* Jenk.
Oligocene	Limestone (Lower)	Cebú, Batan Island	—	—	*Nummulites niasi* Verb.
Age uncertain probably Tertiary	Crystalline schists and gneisses	Camarines	Camarines, Ilocos N., Cebú, Zamboanga Pen., Romblon Is.	Gold, mica, talc, apatite, hematite, magnetite	
	Iron formation	Bulacan			
	Granites	—	—	—	
Unconform.(?)	— — — — — — — —	— — — — — —	— — — — — — — —	— — — — — — — —	
Pre-tertiary	Quartz porphyry	Lepanto	Central and northern Luzon	Copper ores	
	Diorites	Benguet	North. Luzon, Leyte, Panay	Gold, tellurium, silver	
	Gabbros	Leyte	Leyte, Mindanao, etc.	—	
	Pyroxenite	Ilocos Norte	Ilocos Norte, Zambales Mts. Batan Is.	Serpentine and asbestos	
	Peridotite	Near Olongapo	—	—	

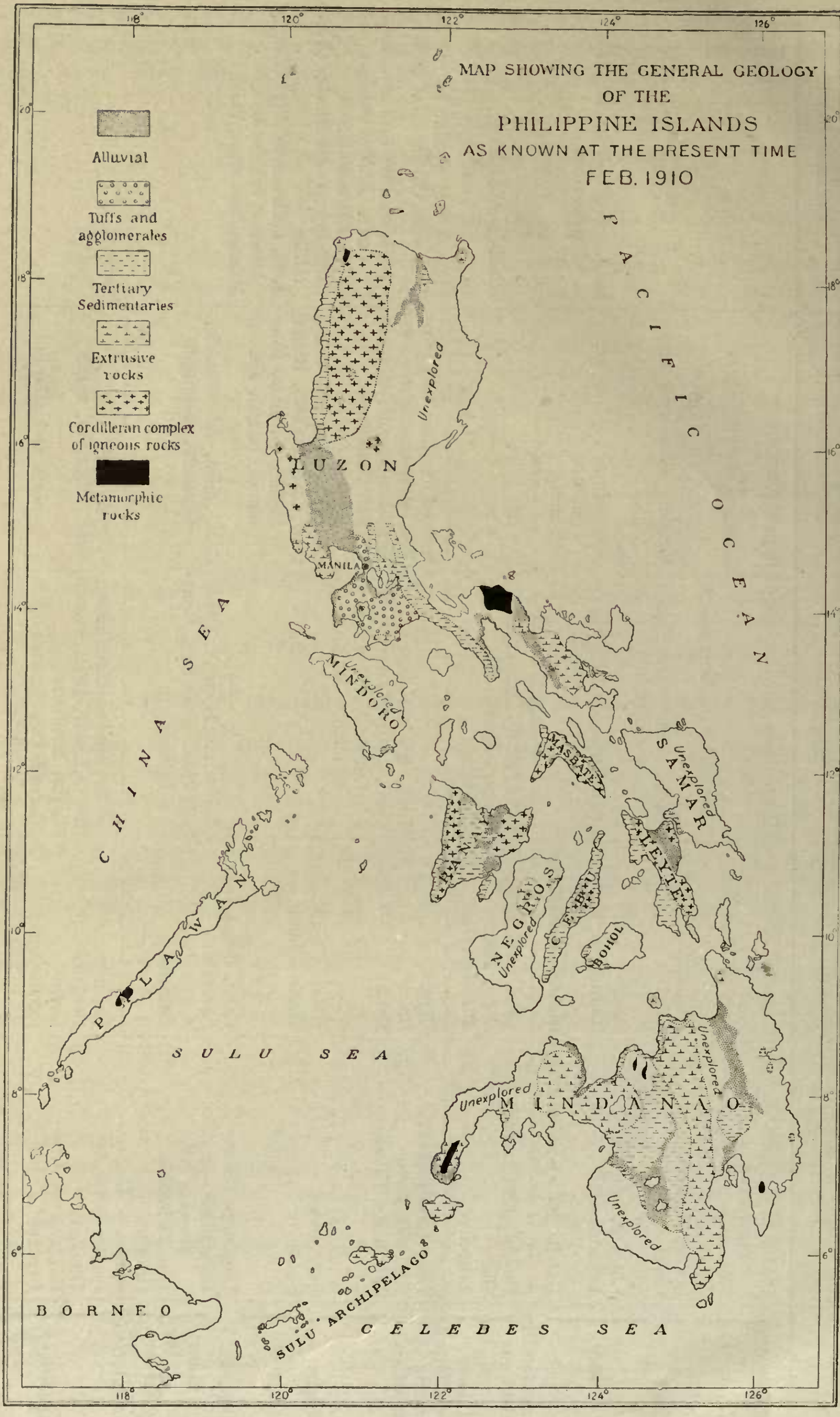
MAP SHOWING THE GENERAL GEOLOGY
OF THE
PHILIPPINE ISLANDS
AS KNOWN AT THE PRESENT TIME
FEB. 1910
Alluvial
Tuffs and agglomerates
Tertiary Sedimentaries
Extrusive rocks
Cordilleran complex of igneous rocks
Metamorphic rocks
PACIFIC OCEAN
CHINA SEA
LUZON
MANILA
Unexplored
MINDORO
MASBATE
SAMAR
LEYTE
PANAY
NEGROS
CEBU
BOHOL
PALAWAN
SULU SEA
MINDANAO
SULU ARCHIPELAGO
CELEBES SEA
BORNEO
118°
120°
122°
124°
126°
6°
8°
10°
12°
14°
16°
18°
20°

Fig. 4.

The Divisions of the Philippine Tertiary (after H. Douvillé).

		Philippines.			Borneo.	
II.	a.	Upper Limestone with small Lepidocyclines	Lep. cf. Verbeeki, Miogypsina	H.	Burdigalien	Miocene
	b.	Sandstone and shale	Cycloclypeus communis, Orbitolites, Alveolinella, Miogypsina	G. F.	Aquitanien	
	c.	Middle Limestone with large Lepidocyclines	Lep. insulaenatalis, formosa, richthofeni	E.		
I.		Lower Limestone with Nummulites Coal Measures	Nummulites niasi Verb. Amphistegina cf. niasi, Lepidocyclina	D.	Stampien	Upper Oligocene.

As regards distribution, the general statement may be made that the oldest rocks are to be found in the deep cannons of the Cordilleras of Luzon. In many other parts of the Islands where we might hope to find them, we find everything covered by a sheet of volcanic rock, as is the case with much of the western part of Mindanao, or by a mantle of coral limestone, as in Cebú.

Flanking these older rocks, and dipping away from them both to the east and west, are found the Tertiary sediments, limestone, sandstone, shale, and the intercalated coal seams. Above these are found andesitic and basaltic flows, while the youngest consolidated formation of all is limestone. It is not an easy matter in our present state of knowledge to delimit all of these formations. The fact is, many of them which appear to be of different age are in reality contemporaneous. Another noteworthy fact is particularly well exemplified in Cebú; namely, that there is no apparent break in the limestone from the coral reef on the shore to the capping of the Cordillera in the centre of the island at a height of 3000 feet. I have, on that island, walked over a limestone formation which is continuous from the living coral reefs to the Pliocene, and probably the Miocene, with apparently no unconformity. In fact, this island after the Miocene deformation must have suffered a long period of erosion, and probably sank below sealevel and subsequently rose very slowly from the sea, so gradually that the whole island was covered with a mantle of coral limestone. This mantle has since been largely removed by erosion.

On Fig. 4 I have attempted to present a map showing the present status of our knowledge of the general geology of the Philippines.

Partial List of Genera and Species of Philippine Fossils.

Arca nodosa Mart.; *Arca hispida* Phil.; *Aequipecten; Alectryonia folium* Lam.; *Amusiopecten burdigalensis var. elongata* Sacco; *Astarte; Balanophyllia; Bulla; Callianassa Dijki* Mart.; *Campanile; Capulus; Cassis pila* Reeve; *Cassis nodulosa* Gmelin; *Cassis herklotzi (?)* Mart.; *Cardita boettgeri* Mart.; *Cardium rugosum* Lam.; *Cerithium karangense* Mart.; *Cerithium (Vicarya) callosum* Jenk. *var. Semperi* Mart.; *Cerithium (Campanile) vicentium; Chama; Clementia papyra (?)* Gray; *Conus sinensis* Low.; *Conus sulcatus* Reeve; *Conus vimineus* Reeve; *Conus odengensis* Mart.; *Conus acutangulus (?)* Chemn.; *Conus socialis (?); Conus hardi (?); Conus striatellus* Jenk.; *Corbula tunicata* Hinds.; *Cultellus maximus* Gmelin; *Cycloseris decipiens; Cycloseris hildalgi* Smith; *Cypraea poraria (?)* Lin.; *Cypraea paniculus (?)* Bttg.; *Cytherea javana* Mart. *Cytherea ventricola (?); Dentalium; Dictyaraea (?) micantha* Reuss; *Dione; Dolium costatum* Desh.; *Dosinia boettgeri* Mart.; *Dosinia plana (?)* Reeve; *Drillia (?) weberi* Smith; *Euthria; Flabellum australe (?); Fusus cortada sp. nov. (?); Fusus rostratus (?); Fusus tjidamarensis* Mart.; *Fusus (Cyrtulus) verbeeki* Mart.; *Glossostylus picturatus* Pfeiffer; *Gryphaea; Hindsia dijki* Mart.

Lagunum (?); Lepidocyclina richthofeni Smith; *Lucina; Lucina (Codakia) semperiana (?)* Issel; *Macoma rosareana* Smith; *Madracis; Melania laterita* Lea; *Melania denticulata* Lea; *Melania woodwardi* Mart.; *Morio echinophora* Lin.; *Nassa verbeeki* Mart.; *Nassa cassiculata* Lam.; *Nassa siquijorensis; Natica mamilla; Natica globosa* Chemn.; *Natica marochiensis* Gmelin; *Natica rostellina (?)* Jenk.; *Natica ovum* Mart.; *Natica callosior* Mart.; *Nerita punctata* Smith; *Nummulites niasi* Verbeek; *Odontocyathus; Oliva (ancilla); Orbitoides (Lepidocyclina) Martini* Smith; *Ostrea; Pachyseris cristata* Mart.: *Pecten pallium; Pecten subarcualus (?)* Bttg.; *Pecten reticulatus* Reeve; *Pecten leopardus (?); Pecten senatorius* Gmel.; *Pecten javanus* Mart. *(?) Phos acuminatus* Mart.; *Placuna placenta; Pleurotoma gendinganensis* Mart.; *Pleurotoma carinata* Gray; *var. woodwardi* Mart.; *Pleurotoma flavidula; Pleurotoma nodifera (?)* Lam.; *Plicatula imbricata* Menke; *Potamides palustris* Lin.; *Potamides herklotzi (?)* Mart.; *Psammobia tenuis* Desh.; *Pteropsis (?) bullata* Smith; *Ranella spinosa* Lam.; *Ranella nobilis* Reeve; *Ranella subgranosa* Beck; *Rostellaria javana* Mart.; *Schizaster subrhomboidalis; Septaria arenaria* Lam.; *Semele (?) dalli* Smith; *Stephanocoenia; Strombus javanus* Mart. *var. Semperi* Sm.; *Tagelus coribaeus (?)* Lam.; *Tagelus coarctatus* Gmelin; *Tapes lobooënsis* Smith; *Tellina plicata* Valenc *(?)*; *Teridina annulata (?)* Bttg.; *Tritonidea ventricosa* Mart.; *Trochus; Turbo bornеënsis* Bttg.; *Turbo nivosus* Reeve; *Turricula jonkeri* Mart.; *Turricula bataviana; Turritella terebra* Lam.; *Turritella cingulifera* Sow.; *Venus pulcherrima (?)* Mart.; *Venus sqamosa* Lam.; *Venus chlorotica; Vermetus junghuhni* Mart.; *Vicarya callosa* Jenk. *var. Semperi* Sm ; *Voluta pellis serpentis* Lin. *(?)*

B. Lithology

by **J. P. Iddings.**

The rocks of the Philippines Islands, so far as known are:

1. The igneous rocks that form the volcanoes and principal mountain ranges, and consist of massive lavas, both extrusive and intrusive, and to a larger extent, perhaps of tuffs and aerial breccias. These rocks not only form the cones and slopes of the volcanic mountains but extend in certain regions over the plains and valleys, and mingle with the sand and coral limestones which make up the sedimentary rocks of the islands.

2. The igneous rocks that have solidified at some depth beneath the surface, and in places have been considerably metarmorphosed by shearing and recrystallization, and in other ways changed; and that have become exposed through erosion. These rocks appear to be older than the recent volcanic rocks, but may not be older than the earliest tertiary formations. They may be exposed intrusions of the volcanic lavas that form the older portions of the volcanic mountains mentioned in the first paragraph.

3. The sedimentary deposits that have been derived from the igneous masses by disintegration in some instances; and by degradation of tuff deposits, or by direct sedimentation of such volcanic material at the time of its eruption, together with such other sediments as may have been derived from coral reefs, and other rocks.

1. Rocks of the volcanic mountains.

The great bulk of all the volcanic rocks of the islands is andesite, for the most part pyroxene-andesites, in which hypersthene and augite are both present, the orthorhombic pyroxene often in great abundance. A considerable proportion of the andesites carry hornblende besides pyroxene, and are hornblende-pyroxene-andesites. A smaller number are hornblende-andesites without pyroxene, and fewer contain biotite in addition to the ferromagnesian minerals already named. Some pyroxene-andesites carry small amounts of olivine, and form transitions between andesite and basalt.

Basalts with variable amount of olivine are abundant, and constitute some of the more prominent and the more active volcanoes. On the other hand dacites, and possibly rhyolites, are rare, so far as known, and occur in relatively small bodies.

Certain basaltic rocks characterized by rather alkalic feldspar, and in one case by altered leucite, are found in several localities.

Pyroxene-andesite. In most instances these rocks are dark colored, dense or porous, less often vesicular: porphyritic with many small phenocrysts, that is, they are mediophyric. The relative amounts of phenocrysts and groundmass vary somewhat in different cases but the great majority have nearly equal amounts of phenocrysts and groundmass (sempatic), or have rather more groundmass (dopatic). Several of the freshest varieties collected may be described as follows: From Cochinos Point and Sisiman, Bataan Prov. Mariveles. A dark colored sempatic, mediophyric rock; that is, one having many small phenocrysts, about as much in bulk as the groundmass, containing them. The phenocrysts are mostly labradorite, approximately Ab_2 An_3, with pronounced zonal structure, the narrow outermost zone being distinctly alkalic. The shapes are those of rectangular prismoid to equant crystals. In size they are seriate, that is, of different sizes from those of several millimeters to less than 1 millimeter. They are well twinned, in Carlsbad, albite and pericline manner. They contain many microscopic inclusions usually in the central portion of each crystal. There are fewer phenocrysts of hypersthene and augite, the former faintly pleochroic in thin section. Augite is twinned in some cases, and occasionally surrounds hypersthene. The pyroxene phenocrysts are euhedral, with the first and second pinacoids strongly developed. In size they are generally smaller than the largest feldspar. There is considerable magnetite in small crystals. Those inclosed in pyroxene are smaller than others, not so inclosed. Some are inclosed in the margin of the feldspar. The groundmass consists of microlites crowded together: rectangular equant, also prismoid plagioclase feldspar, prismoid pyroxene, and equant magnetite; probably with a cementing matrix of colorless glass.

An olivine-bearing pyroxene-andesite occurs at Antipolo, Rizal Province. It is dopatic, with preponderance of groundmass; is mediophyric, and has a hyatal, to seriate, porphyritic fabric. There are many phenocrysts of labradorite, with abundant inclusions; few of pyroxene and some olivine. The groundmass consists of colorless glass crowded with brown globulites, and many microlites of prismoid plagioclase, equant to prismoid pyroxene, equant magnetite, and many minute long needle-like crystals of pyroxene, and lines of globulites, which are undoubtedly pyroxene also. Some are in attached strings, some are disconnected, This variety of rock is intermediate between andesite and basalt.

Hornblende-pyroxene-andesites are very similar to pyroxene-andesites in composition except for the presence of variable amounts of hornblende, and generally smaller amounts of hypersthene. They resemble them also in texture, having similar habit and like variations in the fabric of the groundmass. There are varieties with little hornblende which grade by increasing amounts of this mineral and decreasing amounts of pyroxene into hornblende-andesites. A few rocks of this group contain small amounts of olivine. They are not so abundant in the Islands as pyroxene-andesite, judging from the collections already made, and occur intimately associated with them in various localities.

An olivine-bearing variety occurs in Mindanao. The hornblende is brown, the pyroxene is augite; there is a little colorless olivine, and possibly a little biotite. The groundmass is pumiceous and glassy, crowded with microlites of feldspar, pyroxene and magnetite.

Hornblende-andesite, with little or no pyroxene, is of widespread occurrence. Its habit varies considerably, some varieties are magnophyric with abundant large phenocrysts of plagioclase about 10 millimeters in diameter, and smaller ones of hornblende. These are the rocks that were formerly called „trachytes".

The light colored rock at Sisiman which is used in the Manila Breakwater is hornblende-andesite. It is sempatic, seriate and mediophyric. The most abundant phenocrysts are labradorite, Ab_2 An_3, euhedral and subhedral. They possess a narrow outer zone of distinctly more alkalic feldspar, which, however, has noticeably higher refraction than the anhedral feldspar of the surrounding groundmass. The hornblende is greenish brown, but is mostly paramorphosed into aggregates of magnetite and pyroxene. There are few phenocrysts of pyroxene and relatively large ones of magnetite. The groundmass is holocrystalline, composed of consertal anhedrons of feldspar, in part probably orthoclase, with some quartz. The rock is somewhat altered in parts, and contains calcite and (?) chalcedony.

Hornblende-biotite-andesite is found among the river gravels at Montalban. It is sempatic, seriate and mediophyric. The plagioclase phenocrysts are euhedral, zonally developed, and approximately Ab_1 An_1. The biotite is brown, the hornblende in this case altered; There is magnetite and colorless apatite. The groundmass is microgranular, and consists of rectangular euhedral plagioclase with consertal anhedral feldspar, and micropoikilitic quartz.

Dacites are not as common as the andesites and the few specimens collected are in part noticeably porphyritic, in part megascopically nonporphyritic.

One from Benguet is sempatic and hyatal mediophyric, that is, there is a sharp contrast between the size of the smaller phenocrysts and the grain of the groundmass. There are many rather large phenocrysts of plagioclase, with slightly rounded euhedral forms, distinctly zonal; fewer and smaller phenocrysts of green hornblende, brown biotite, and still fewer of subhedral, rounded, quartz; and some magnetite. The groundmass is micro-cryptocrystalline.

On Corregidor Island massive dacite occurs which is white and dopatic, and seriate mediophyric. The phenocrysts are glassy plagioclase, quartz and biotite, megascopically black, and euhedral. The groundmass is holocrystalline and seriate microporphyritic, consisting of small phenocrysts of prismoid plagioclase, probably andesine oligoclase, and abundant, euhedral bipyramidal quartzes[6], in a microcrystalline matrix of anhedral quartz and intersertal alkalic feldspar.

Basalts. There are transitions between olivine-bearing pyroxene andesites and basalts in olivine, so here are basalts with the texture found in andesite, and others with textures not developed in andesites. No line can be drawn between these two groups of rocks and petrographers differ as to the classification of rocks intermediate between basalts and andesites. It happens that the lavas of Mayon and Taal volcanoes belong in part to these intermediate varieties, which may be called olivine-bearing pyroxene-andesites or andesitic basalts, while other varieties of lava from these volcanoes are normal basalts, with abundant olivine.

Basalts with andesitic habit occur in the Batanes. In two cases the rocks have the composition of hypersthene-augite-andesite with small phenocrysts of colorless olivine partly altered to iddingsite, the groundmass being holocrystalline, with anhedral feldspars. These are probably best called olivine-bearing pyroxene-andesites.

Varieties with andesitic habit and much olivine occur at Mt. Mariveles in Bataan and in Mindanao. In both of these rocks the olivine is present as small colorless crystals in part altered to red iddingsite.

Basalt from the floor of the crater of Taal volcano is dopatic, mediophyric, with phenocrysts of subhedral, green augite, having inclusions to zones in some crystals; subhedral, equant to tabular labradorite, $Ab_2\ An_3$ — $Ab_1\ An_2$, zonally developed; and fewer colorless to yellow olivine, altered on the surface of the crystals. The augite and labradorite are anhedral toward each other when in clusters. The olivine in some instances is partly inclosed in augite, with anhedral forms. The groundmass consists of euhedral prismoid plagioclase, with central euhedral prismoid inclusion that has much lower refraction and is isotropic, apparently glass. The plagioclase prismoids have diverse arrangement. There is also much equant anhedral augite, less magnetite, and probably intersertal glass, but the microlites are crowded close together, and the rock may be holocrystalline. Another variety of basalt from Taal volcano is dopatic, medio- to minophyric, and hyatal. The phenocrysts of plagioclase are euhedral, and anhedral fragments, with many minute inclusions, and pockets and cracks filled with groundmass. In one crystal a narrow crack is filled with brown glass containing microlites, whereas the glass of the surrounding groundmass is crowded with them, illustrating differential flow in a partly crystallyzed magma, and the probable origin of differential contemporaneous veins. There are few phenocrysts of olivine and none of augite in the thin section studied. The groundmass consists of equant anhedral augite, much magnetite, less plagioclase, with very little brown glass, scarcely recognizable as such.

Basalt from Mayon volcano, Albay, is dopatic and mediophyric, and highly vesicular or porous. The euhedral, rectangular prismoid, phenocrysts of labradorite contain many inclusions of brown glass; the phenocrysts of green augite are subhedral; those of colorless olivine are subhedral to euhedral. The groundmass is dark brown, globolitic glass with microlites of their needle-like prismoids of plagioclase, and anhedrons of augite and magnetite.

Another rock from this locality, is dopatic, minophyric, with many phenocrysts of augite and colorless olivine, and few of plagioclase. The groundmass is like that of the rock from Mayon Volcano, just described.

Basalts from Mindanao differ somewhat from those already described from Luzon in being richer in ferromagnesian minerals, and in having plagioclase slightly less calcic.

Basalt from the Lanao District, Mindanao, is dopatic, mediophyric, and seriate, with

many phenocrysts of olivine, but slightly altered, and with inclusions of magnetite. The groundmass consists of much anhedral augite, some anhedral olivine, less magnetite, and prismoid plagioclase about equal to the ferromagnesian minerals in amount. The composition of the plagioclase is not readily determinable, it is as calcic as andesine. There is a small amount of colorless matrix with lower refraction, which may be glass.

On Masbate some of the volcanic rocks differ notably from most of those found elsewhere in the islands, in that they appear to contain higher amounts of potash, which shows itself in orthoclase, mica, and what was probably originally leucite. It is possible that related rocks will be found in other parts of the Archipelago when more thoroughly explored. These rocks have undergone considerable alteration and their exact composition is not readily determinable from the sections studied.

The rock from about 2 kilometers south-west of Aroroy is dark gray, sempatic, mediophyric, and seriate; the diameters of the phenocrysts varying from 5 millimeters to less than 1 millimeter. They are chiefly euhedral, twinned augite, greenish, with faint pleochroism, from green to yellow; clusters of equant colorless crystals, and some isolated euhedral of the same mineral, which appears to be leucite, possibly altered to analcite, as it does not exhibit birefrigence. There are some small phenocrysts of plagioclase, partly altered and probably alkalic, or calci-alkalic. The augite phenocrysts are zonally developed, with „hour glass“ structure in some cases. They contain glass inclusions and small crystals of magnetite. Surrounding the phenocrysts, especially the augite, there are dark clusters of minute crystals that extend to various distances into the groundmass. They are needles and minute prismoids of augite in subparallel clusters. In places they seem to be granulated, or coarsely globulitic. With these prismoids are mingled opaque needles, or blades, of what suggest ilmenite, but from their resemblance to similarly shaped, and arranged blades of brown mica, present in closely related rocks of this locality, they may be paramorphic mica. They are in sets, or groups, of parallelly arranged prismoids, often at different angles in the matrix, or in ferule-like arrangement; a set of minute, parallel blades being crossed by a large one like a stem.

The clusters of colorless (?) leucite have the form of leucite crystals, are euhedral to subhedral, in some cases rounded.

Some carry minute inclusions, centrally located, less often zonally. In several finer grained varieties of the rock there are minute, imperfect, skeleton forms, characteristic of leucite. The groundmass consists of indistinctly outlined, clouded feldspar, possibly orthoclase in part, besides products of alteration. In the finer grained variety the prismoid and needlelike alkalic plagioclase is more distinct. There are prismoids of augite, and groups of parallel needles or blades of pale brownish, pleochroic mica.

2. Coarser grained igneous rocks.

Syenite. A medium to fine grained rock occurs about 1 mile east of the summit of Mt. Aroroy on Masbate. It is non-porphyritic and consists of rectangular prismoid, to equant, anhedral feldspars, that are to some extent twinned in the Carlsbad manner, as a cloudy orthoclase, probably sodic. Their arrangement is diverse. There is a subordinate amount of ferromagnesian minerals in smaller crystals included in the feldspars, and also intersertal to them. They are chiefly brown mica, partly chloritized, diverse in arrangement; some magnetite, and long thin needle-like crystals of apatite, also with diverse arrangement. There is some scattered chlorite, epidote and secondary quartz.

There are rocks in the collection that are normal gabbros with inequigranular consertal fabric, sometimes called „granitic", and others with ophitic fabric, also called „diabasitic". They grade through finer grained porphyritic varieties into holocrystalline pyroxene-andesites and basalts. They also grade into diorites and quartz-diorites by variations in the mineral composition, just as the basalts grade into pyroxene-andesites, and these into hornblende-andesites and dacites.

The alteration of pyroxene into fibrous amphibole, uralite, and also into compact hornblende in some instances, leads to the metamorphism of some of the gabbros into metadiorite, which in such cases is usually recognized by the character of the feldspar, and the texture of the rock.

The extremes of this mineral variation, or differentiation in this region appear to be albitic granite and albitic syenite on the one hand, and peridotite and possibly pyroxenite on the other.

There are not sufficient data at hand to determine the relative abundance of the different magmas and so indicate the composition of the average or „parent" Magma. It appears that the coarse grained, intrusive, rocks have attained a higher degree of differentiation than the extrusive lavas, but this may not be actual fact, and further study of the region may modify this conclusion.

The best known active volcanoes are erupting lavas that are not extremely differentiated. The modern lavas are not all alike, and some of the older ones are highly differentiated from the probable parent magma, as for example the dacite on Corregidor and leucite rock in Masbate.

Gabbro. The gabbros with consertal, inequigranular fabric, vary from those with nearly equigranular feldspars to others with intersertal fabric, due to the abundance of smaller crystals between the larger ones. There is thus a transition to seriate porphyritic fabric, and the texture of some holocrystalline andesites. The similarity of the component minerals also indicates a generic relation between these coarser rocks and the extrusive lavas in this region. Some of the freshest examples in the collection will be described.

An olivine-gabbro occurs in river gravel at Montalban. It is medium to coarse grained, inequigranular, consertal, and consists of labradorite, $Ab_2\ An_3$, pale green augite, colorless olivine, and very small amounts of primary hornblende, biotite, and magnetite with some secondary minerals locally developed. The proportion of feldspar to ferromagnesian minerals is about 3:1.

The labradorite is anhedral, zonal structure, is somewhat twinned according to the three common laws, albite, pericline and Carlsbad; and contains a small amount of minute rod-like inclusions. The augite is anhedral; has a distinct pinacoidal cleavage, characteristic of diallage; is twinned and contains rod-like inclusions. The olivine is also anhedral: in places it is intersertal with respect to the labradorite, showing its later crystallization. There is a narrow border of minute anhedrons, probably amphibole, between the olivine and labradorite. The proportion of augite to olivine is about 6:1. Primary green hornblende surrounds augite and magnetite in some places and the light brown biotite, in very small amount is associated with the hornblende. The magnetite is associated with the augite, in juxtaposition and also intersertal between augite anhedrons. The intersertal position of much of the augite, olivine, magnetite and primary hornblende between the larger anhedrons of labradorite indicates the synchronous crystallization of the ferromagnesian constituents together with some labradorite, as the last act of the crystallization of the magma, after much feldspar had crystallized. In places this rock is altered, and secondary green hornblende has been formed in narrow veins traversing altered feldspar and other minerals. This shows the ordinary metamorphism and metadiorite. Olivinegabbro similar to that just described in texture and composition occurs in Albay Province.

A coarser grained olivine-gabbro of this type occurs in Nueva Viscaya. The labradorite is more abundant, and is about five times as much as the olivine and scarce augite. There is no magnetite, but some secondary amphibole.

A very fine grained norite occurs on Palawan having the composition approximately of 50 feldspar, 40 pyroxene, 10 magnetite. The fabric is nearly equigranular, consertal. The labradorite is anhedral and somewhat larger than the crystals of pyroxene. They contain small inclusions of euhedral pyroxene and magnetite. The pyroxene is mostly hypersthene, in nearly equant subhedrons and rounded anhedrons. Gabbros with ophitic fabric which are sometimes called „diabase", dolerite or phanerocrystalline basalt, occur in numerous localities in the Archipelago. But most of those already collected are more or less decomposed, or metamorphosed. They are characterized by prismoid, or tabular, plagioclase, with diverse, less often subparallel, arrangement; and by poikilitic, or intersertal, pyroxene that acts as a matrix for the feldspar. They grade into varieties in which the intersertal matrix is formed of several crystals of more than one mineral, as in some basalts.

Metadiorite which appears to be metamorphosed gabbro is of frequent occurrence. That from Malitbog, Leyte, is medium grained, inequigranular and consertal, and consists of labradorite, without zonal structure, and green hornblende, both compact and fibrous.

Diorites, which are plagioclase rocks characterized by notable amounts of primary hornblende, are related to hornblende-gabbro on the one hand, and to quartz-biotite-diorite on the other. They may be confused with metadiorite, in which the hornblende is not pyrogenetic.

Near Atimonan, Tayabas Province, there is medium grained, inequigranular, consertal diorite, which may possibly be hornblende-gabbro. The labradorite is like that common in gabbro; without zonal structure, and containing numerous rod-like inclusions. The hornblende is anhedral, and green, with numerous rounded inclusions. There is a small amount of mica altered to chlorite. Magnetite is in part intersertal.

Diorites rich in hornblende occur in Cebú, one from the Island of Palawan corresponds in general texture to the fine grained norite already described from this island. Its fabric is consertal, anhedral, equigranular, or nearly so. It consists of nearly equal amounts of labradorite and brownish green hornblende. Within the feldspar are small euhedral inclusions of hornblende and magnetite; and within the hornblende anhedrons there are small anhedral inclusions of feldspar and magnetite.

Quartz-diorites occur in different parts of the Islands. In Benguet (Mountain Province) there is medium grained quartz-diorite, with inequigranular consertal fabric. It consists of plagioclase and considerable brownish green hornblende, anhedral with respect to each other but euhedral toward quartz and orthoclase. There is some altered biotite. In places the orthoclase is intersertal to poikilitic with inclusions of plagioclase and hornblende. Another quartz-diorite, Camarines Province, has the same texture as that just described, but there is less hornblende, and more quartz. The plagioclase is probably zonal andesine, with the outermost zone more alkalic. Other quartz-diorites have been found near Talisay and in the Loboo Mountains in Batangas Province, in Masbate, in Lepanto, and elsewhere.

Granite is rather an uncommon rock, so far as present observations go, and the few bodies of granite known are somewhat metamorphosed, or altered. That found near Paracale, Ambos Camarines, has a gneissoid texture; is medium to fine-grained, and consists of white feldspar and quartz and dark green chloritized mica. It is inequigranular, with equant anhedral feldspar and quartz crystals, with smaller amount of intersertal anhedrons of the same minerals, besides chloritized mica, and epidote. The feldspars are orthoclase, and less oligoclase, or albite. There is considerable quartz.

The granite at Mambulao has been sheared to a thinly laminated gneiss with „augen-structure“ on a small scale. The orthoclase and albite lie as anhedral blocks in a matrix of smaller equant anhedrons of quartz and orthoclase with shreds of muscovite, having pronounced fluxion structure.

Note on the Metamorphic Rocks by Warren D. Smith.

Metamorphic rocks are found in scattered patches in many portions of the Archipelago, and they are naturally to be found in or flanking the mountainous areas. Some are derived from igneous rocks and some from sedimentary rocks. Their age is uncertain, many are undoubtedly Tertiary. That any of them are Archean is extremely doubtful. There are absolutely no reasons at hand now for supposing that any of those known or those that are yet to be discovered are as old as the Archean.

We have gneisses, schists, serpentines, etc. In Ilocos Norte we have serpentines, amphibolites and magnetite schists. In Romblon marble and micaschists are found. The marble is metamorphosed limestone, and the micaschists were derived in all probability from Tertiary sandstones and shales. In Cebú on the flanks of the cordillera are some schists of unknown origin. In the lower Zamboanga peninsula there is a considerable exposure of quartz-sericite schist which may represent metamorphosed sediments, though I am not yet certain of this. In Ambos Camarines we have gneissic granite, schistose diorite, slates and brecciated sandstones. In my opinion, we can argue nothing from the presence of schists as to age. Metamorphics are products of dynamism and may be of any age.

III. Orographic Elements.

Coastal Plains.

The various islands of the Archipelago are, as is the case with many recent islands, characteristically lacking in any considerable development of coastal plain. And it is due to this fact more than to any other, probably, that the country is so backward in commercial development. Nearly everywhere the mountains border the coast very closely. Fringing the coast line throughout most of its length, are to be found coral reefs. Where these have been elevated and covered with a veneer of piedmont deposits we have a coastal plain. Nowhere is this coastal plain much over 10 or 15 kilometers in width, and it is exceedingly broken, thus interrupting the easiest line of communication by land. The only stretches of coastal plain of any importance are the Zamboanga plain, some narrow strips on the east and west coasts of Cebú, much wider belts on Negros, the chief sugar producing island, a portion of the eastern part of Leyte, and possibly we should consider the Iloilo plain, though strictly speaking this is intermontane.

The Intermontane Plains.

The large, more or less flat and fertile tracts which lie between the cordilleras are, with one or two notable exceptions, the sites of the chief human activity in these Islands. These plains owe their origin partly to elevation of the trough between what were once islands, and subsequent upbuilding by delta deposits, alluvial fans, and pyroclastic material.

The principal ones are:

1. The central plain of Luzon, from Manila Bay to Lingayen Gulf.
2. The Cagayan Valley (northern Luzon).
3. The central plain of Panay.
4. The valley of the Agusan (eastern Mindanao).
5. The Cotabato Valley (central Mindanao).

The Cagayan Valley is perhaps the most fertile of them all, and is where most of the Philippine tobacco is grown. The central plain of Luzon is largely cultivated for rice. Much of this land, however, is unproductive. Irrigation will do much to reclaim it. The central plain of Panay is one of the seats of the sugar industry. The Cotabato Valley plain is occupied largely by Maguindanao Moros and produces only a modicum of what it is capable.

The Intermediate Uplands.

Under this heading I shall consider all that upland territory between the foothills and an elevation of 4,500 feet. This will include the rolling grass covered hills of Cebú, Masbate etc., the smaller forest clad ranges of Luzon, the fertile slopes of such volcanoes as Mayón, Canlaón, Apó, etc., and such semi-plateau areas as Baguio in Luzon, and the Lanao district in Mindanao.

At present, only the poorest people live in the uplands, but when the mineral and forestry resources of the Islands come to receive their due share of attention this zone, if it be not the abode of the wealthiest, will probably furnish the larger portion of the wealth of the Islands. This upland zone probably includes 75 per cent of the whole landarea of the Philippines.

The principal rocks of the upland zone are the Tertiary sedimentaries with some recent volcanics which flank the igneous cores of the cordilleras. They are found in-

clined at all angles. There are notable exceptions to this, however. Some of the upland country, like that of a part of northern Masbate, for instance, is denuded of sediments and characterized by old worn down volcanic stocks, while the uplands of western Mindanao are covered by a sheet of basalt.

The Cordilleras.

It is difficult to make a hard and fast distinction, one that is genetic, between the intermediate uplands and the cordilleras. It is quite clear that a true cordillera may not in its highest parts reach the upper limits I have already placed for the intermediate uplands. For instance, in the Island of Cebú the highest point is not much over 3,000 feet, but the central range in this island, which varies from 2,000 to 3,000 feet, is as wild and uninhabitable as the central range in Luzon which attains to a height of over 8,000 feet, and technically it is just as much a cordillera.

The principal cordilleras are the Sierra Madre Range (northeast Luzon), the great Cordillera Central (from Benguet northward to the Pacific Ocean), the Zambales Range (Western Luzon), the central ranges of the various Visayan Islands, (Panay, Negros, Cebú, Leyte, Samar, Masbate), most of which have only one large central range with two or more secondary ones which are lower and, therefore, come into the category of the intermediate upland. In Panay there are two fairly well defined cordilleras, an eastern and a western.

The Island of Palawan is practically cordillera and little else. It belongs to the Mindoro-Busuanga-Palawan system.

In Mindanao, there is a cordillera of only moderate height extending along the Zamboanga Peninsula; a group of fairly high peaks in a cluster about Lake Lanao, a very irregular group of high points in southern Mindanao, and a well defined north and south range east of the Agusan River; but the continuous and high range usually shown on Spanish maps, in line with Mounts Apó and Matutan, does not exist. The country is quite low for the most part, and instead of there being a well defined cordillera there are only a few high points at wide intervals. 1950 feet was the highest point on the trail which crosses this range.

The cordillera is, as a rule, very forbidding country in the Philippines, being the home of the most primitive people such as Negritos in Luzon, Manobos in Mindanao, and also the haunts of brigands (ladrones as they are called here). (See Fig. 5 for the situation of the principal cordilleras.)

Volcanoes.

The writer has made no special studies of the volcanoes of the Philippines. Mr. H. G. Ferguson, my colleague, has been collecting data on this subject for the past three years and he intends to publish a paper on this subject in the near future. I, therefore, have quoted the following introductory remarks:

„The many volcanoes in the long chain of islands festooning the continent of Asia, from Burma, to Alaska, for the most part fall into definite zones; most clearly so in the Islands of the Dutch East Indies. In the Philippines there are also several well defined belts of volcanoes. Becker[7] has shown that for the southern islands of the archipelago there are two main curved fissure systems intersecting at an angle of about 60°. One of these lines he regards as containing the group of extinct volcanoes forming the Island of Cagayan and Jolo, the Cagayanes Islands, and extruding through Panay. A second and better marked line, belonging to the same system, starts from Darvel Bay in Borneo and contains in the Sulu Archipelago many recently extinct volcanoes; and in the northward continuation the two volcanoes of Negros, Tigas and Canlaon. The positions of the volcanoes of Mindanao relative to the two main fissures

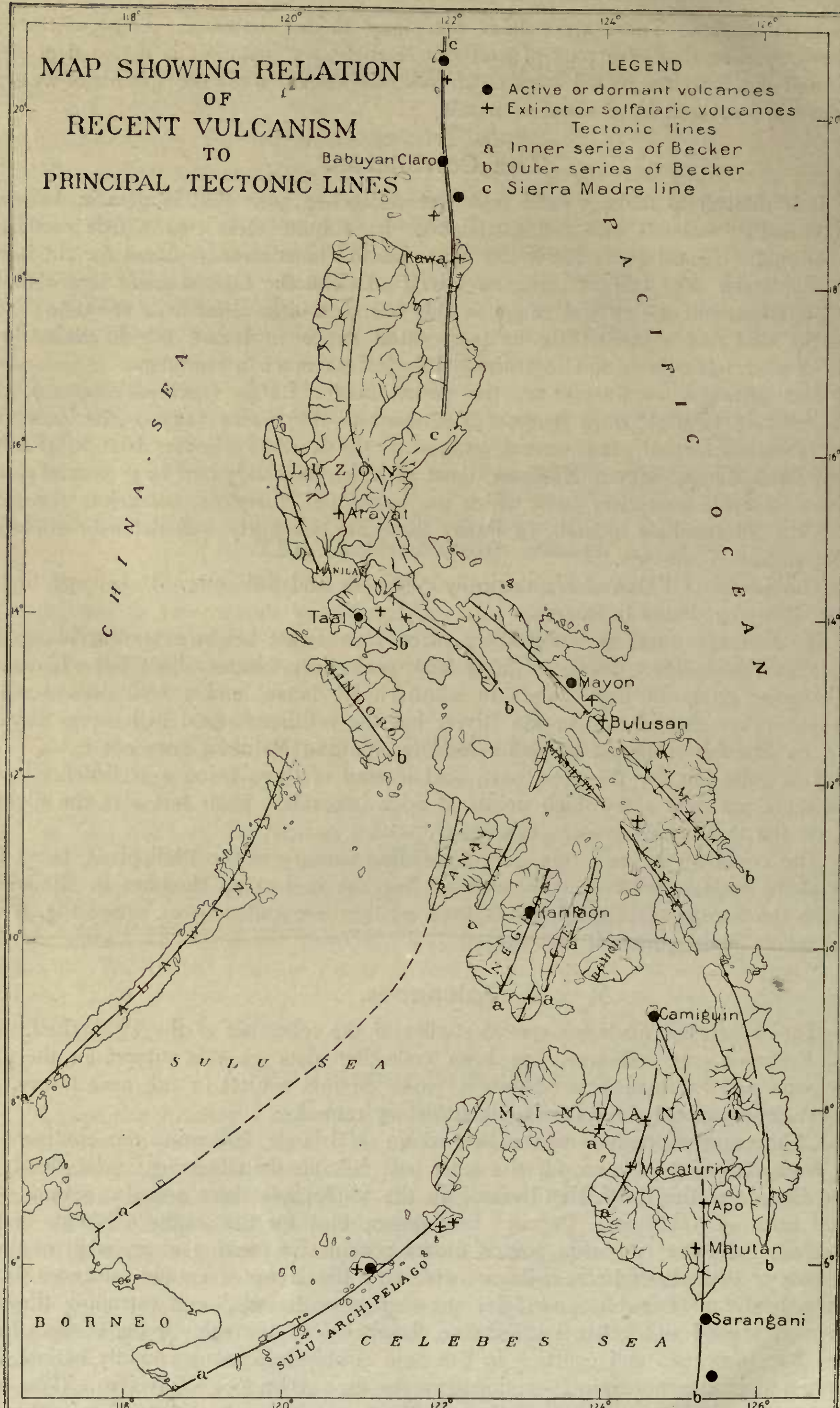
MAP SHOWING RELATION
OF
RECENT VULCANISM
TO
PRINCIPAL TECTONIC LINES
LEGEND
● Active or dormant volcanoes
+ Extinct or solfataric volcanoes
Tectonic lines
a Inner series of Becker
b Outer series of Becker
c Sierra Madre line
118°
120°
122°
124°
126°
20°
18°
16°
14°
12°
10°
8°
6°
Babuyan Claro
Kawa
LUZON
Arayat
MANILA
Taal
MINDORO
Mayon
Bulusan
PANAY
NEGROS
Kanlaon
Camiguin
MINDANAO
Macaturin
Apo
Matutan
Sarangani
SULU ARCHIPELAGO
BORNEO
PACIFIC OCEAN
CHINA SEA
SULU SEA
CELEBES SEA

Fig. 5.

are not clear, but it is probable that the line of volcanoes extending from northern Celebes through the Sanguir Islands and Sarangani to Mount Apó, and perhaps crossing Mindanao to Camiguin de Misamis, are situated on a fissure of the outer series. Another curve parallel to this extends from the eastern side of the gulf of Davao through the Surigao Peninsula, Leyte and Masbate, and includes the extinct volcano of Diuata in eastern Mindanao and extinct volcanoes in Leyte and Biliran.. A third outer line parallel to the last two is formed by Samar and the Camarines Peninsula of Luzon. Associated with this are the splendid group of volcanoes in Sorsogon, Albay and Camarines provinces, Bulusan, Bacong, Mayón, Iriga, and Isarog.

South of Manila in Laguna and Batangas provinces is a group of volcanoes; one of which, Taal, is still active. These do not seem to fit into either of the two prevailing systems of the Visayan Islands and Southern Luzon, and differ in schemes for classification. Perry[8] classifies the volcanoes of Luzon into three northwesterly lines. The first includes the volcanic stock of Mariveles and Taal Volcano, the second Arayat and Banajao, and the third the Mayon group. Centeno[9] makes one system include Arayat, Taal, Central Mindoro, Canlaon and Macaturin. Koto[10] omits Arayat and the Taal group from his volcanic belt. Becker[11] seems to include the volcanoes of the Taal region with the northwesterly series of fissures and makes no attempt to explain the position of Arayat. North of Arayat there are no known volcanoes until the extreme northwestern part of Luzon is reached. Northward from Kawa a volcanic chain extends due north as far as the Bashi Channel, which separates the Batanes Islands from Formosa."

On Fig. 5 the relation of vulcanism to the tectonic lines, according to our last information, is shown.

IV. Outline of the Geological History.

The dominant episodes in the geologic history are best given in the words of Becker's admirable summary and by adding such comments as later and more intimate acquaintance with the field shows to be necessary.

Mr. Becker says: „. . . . . it would seem that the geological history of the Philippines is something as follows: From early Paleozoic times onward an archipelago has usually marked the position of these islands. Prior to the Eocene nothing definite is known of them, but further investigation will very likely disclose Paleozoic and Mesozoic strata there, as in the Sunda and the Banda islands. During the Eocene it is probable that the lignitic series of Cebú was deposited, and the contorted indurated strata, which in other localities also carry black lignite relatively free from water, should be referred provisionally to this period. Whether the nummulitic limestone found at Binangonan is Eocene seems to me to be an unsolved question. After the Cebúan lignitic epoch a great uplift and folding took place, and this may have been a detail of the late Eocene movement which so profoundly modified Asia and Europe. It must have brought about temporary continuity of land area between Borneo and Luzon. Somewhere about the middle of the Miocene the country sank to a low level. Many of the present islands must then have been far below water, while Luzon and Mindanao were represented by groups of islets. Observations appear to suggest that the Agno beds represent the basal conglomerate formed at this subsidence. A slow rise began again during the later Miocene, and may have continued to the present day without inversion, yet the actual distribution of living forms is such as to give some grounds for believing that, at some intermediate period, the islands were a little higher than they now are, but sank again only to rise afresh. The diorites and associated

massive rocks, including their tuffs, may have made their appearance about the close of the Paleozoic. The less siliceous of these rocks seem to have followed the more siliceous intrusions as a whole. The gold deposits, and perhaps other ores, are so associated with these massive rocks as to indicate a genetic relation. The neovolcanic period began as early as the highest Miocene horizon, and very probably at post-Eocene upheaval. If the semiplastic marls of Cebú are all Miocene, the earlier andesitic rocks, at least, date back nearly to the great upheaval. Among these rocks, also, there is sometimes a tendency for the basalts to follow the andesites, but the one dacite found at Corregidor is later than the andesites of that island. The relation of the trachytes (= hornblendeandesites, see p. 7) to the andesites is not certain, but the sanidine rock is probably the earlier. A very large part of the neo-vulcanic ejecta has fallen into water and been rearranged as tuffaceous plains", as the following section of a well at Pasay, Rizal Prov., Luzon shows:

Section of Well at Pasay, Rizal Prov. Luzon, P. J.

0	to	18	ft.	soil, sand and sea shells;
18	„	83	„	gray and yellow silt with pebbles, shells and calcareous concretions;
83	„	87	„	fine to coarse basaltic pebbles and tuff;
87	„	113	„	yellow gray sand, some clay, fragments of soft tuff;
113	„	160	„	yellow gray tuff;
160	„	180	„	yellow sand and tuff, small basaltic pebbles;
180	„	463	„	light, yellow, gray tuff, partially with basaltic pebbles;
463	„	483	„	fine dark sand, some clear grains, tuff, basaltic pebbles;
483	„	546	„	fine grained tuff, light gray;
546	„	570	„	dark sand, some clear grains;
570	„	594	„	tuff, with small basaltic pebbles;
594	„	634	„	yellow clay with small basaltic pebbles;
634	„	690	„	dark sand;
690	„	713	„	fine gray tuff;
713	„	743	„	basaltic pebbles and fragments of tuff.

„The volcanic vents appear to me to occur rather on a network of fissures than on a system of parallel diaclases, and the volcanic activity is to be regarded as a thermal manifestation of the energy of upheaval."

As regards the history of the Islands prior to the Eocene, our knowledge is in the same state today than it was when Becker wrote. Furthermore, I am not as hopeful as I was at the beginning of my investigations that Mesozoic and Paleozoic strata will be found. They may by chance be encountered in deep wells, in a deep shaft or in some cannon of the Luzon cordillera. The oldest fossil I have seen from the Philippines is *Nummulites niasi,* which is a typical Oligocene fossil. *Lepidocyclina, Cycloclypeus, Globigerina, Heterostegina, Lithothamnium,* etc., are abundant.

That the Islands have sunk at least once after the formation of the Agno beds (Bued River conglomerate) is attested by the presence of an indurated coral reef above them at a present elevation of over 4,000 feet. This old reef is exposed in Trinidad Cap a few miles north of Baguio. It seems quite probable that the main period of ore deposition followed the Miocene uplift and ended before the deposition of the later sediments. In Masbate the gold bearing veins cut across andesites and diorites indiscriminately. In Benguet they occur, as far as we know, only in the diorite. However, in Benguet ore deposition may still be going on or have only recently ceased. No connection between the instrusives and the ores is certainly known, except the fact that they both follow (in Benguet) east and west or north and south lines of weakness.

V. Economic Geology.

During the three centuries of Spanish occupation very little mining, as we now conceive of it, was carried on. Thousands of Chinese, Filipinos and Moros have made wages through desultory panning for gold; the semi-wild Igorots of northern Luzon have mined and smelted copper and made crude implements; and one Filipina woman has operated for a number of years a crude blast furnace for smelting iron, from which equally crude plough shares are made and used by the natives in southern Luzon.

There were several large mining enterprises started by the Spaniards and English, but there is no record of a single one being other than a failure. (I do not include here the twenty odd arrastras which formerly were operated in the Camarines.)

The year 1905 was practically the beginning year for production in the Islands under the American régime. The gold production in the year 1908 amounted to £ 50000. (For principal mineral districts see Fig. 6.)

The Metals.

Gold. Gold has been found in some quantity in nearly every part of the Archipelago. It was mined in a crude way as far back as we have any records. On the Island of Masbate the writer has been in ancient workings which were probably made by Chinese long before the coming of the Spaniards. The three principal districts where gold mining is now being carried on are Ambos Camarines, Benguet and Masbate. In the first named mining is still largely confined to dredging operations, the vigorous development on the vein deposits is in progress. The country rocks are largely schists and gneisses and slaty shales. The veins are, so far as we now know them, small, but apparently very rich, along the contact or in fissures in the granite near the border. Some larger veins carrying good values have been reported recently. There are two New Zealand dredges in operation and two mills are almost ready to run. These formations are very similar to those found on the islands of the Karimoun Archipelago near Java.

In Benguet the country rock is diorite and the gold is found in fairly large quartz and calcite veins in north and south, and east and west, systems cutting the diorite. Gold occurs, both native and in the telluride. The ore is not entirely free-milling and cyaniding is resorted to. A characteristic of this region is the pretty general absence of oxidation. The main workings are located along the contact between the diorite and the later andesite capping. There are all together 18 stamps dropping at the present time in this district. There are six principal properties on three of which are stamp mills.

In the mining district of Masbate the country rock is largely andesite, which is cut by a system of northwest and southeast quartz veins, one of which is probably over 50 feet wide. The ore is much more oxidized than in Benguet, but only slightly free-milling. A feature of this, as well as of some Benguet ore, is the large amount of manganese oxide in it. There are four principal companies in this district, none of which is in the producing stage at the present time. Other promising districts are: The Surigao Peninsula and the Cagayan-Munigue-Pigtao District (Mindanao), Ragay Gulf-Luzon, Island of Catanduanes, Pangasinan (Prov. Luzon), Mindoro.

Silver. Some silver is found in all the gold districts, usually alloyed with gold. Some native silver occurs in Benguet. Furthermore, practically all the lead is argentiferous. The production in 1908 was 73,100 grs.

Copper. Copper has been found in the form of arsenates and sulphides in the Mancayan-Suyoc district of the Mountain Province of Luzon, as native copper in Masbate, the Camarines and the Island of Jolo.

The best known deposit is that in the Mancayan-Suyoc district. Of this deposit Mr. Eveland[12] says: „In view of the fact that the entire region, with the exception of the one ore body of the Mancayan mine, is in an early stage of development, it is impracticable to

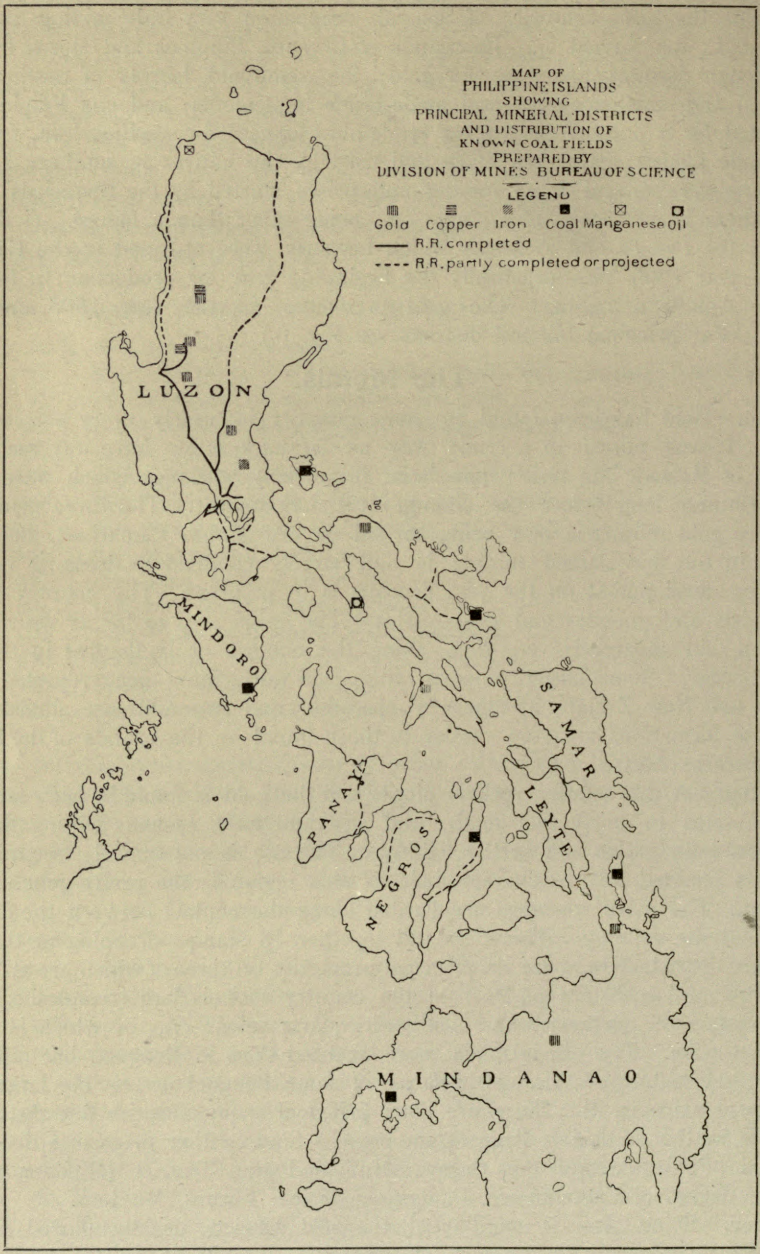

Fig. 6.

treat the ore deposits in detail. It seems to be fairly conclusive, however, that the general type of vein in the district is a narrow quartz lead, carrying metallic sulphides, in some cases of copper, and generally with gold associated in a free state. These veins are in the Man-

cayan diorite which underlies the entire district. With the advent of the trachyte flow, metamorphic changes have taken place and the nature of the country rock altered to a considerable degree." Recent development work has shown this deposit to be rather in the nature of a stockwerk and probably quite extensive.

Lead and Zinc. Lead and zinc are associated in some of the Camarines deposits. Argentiferous lead occurs in many localities, principally in Cebú and the Island of Marinduque. In Cebú it is of the nature of a stockwerk in an andesite flow.

Iron. Iron ore in the form of hematite, magnetite and limonite, with varying percentages of iron, has been found in several localities. There is a fairly well defined belt, however, which follows the east coast of Luzon for a short distance beginning in the Camarines, and then swings into the interior where it reaches, as far as our knowledge now goes, its greatest development near the town of Angat in Bulacan Province. One small blast furnace of crude design is now operated by a Filipina woman.

Analysis by P. L. Stangel (1903): $SiO_2 = 2.24$; $Al_2O_3 = 6.42$; $Fe_2O_3 = 1.92$; $Fe_2O_3 = 88.22$; $MgO = 0.18$; $CaO = 0.12$; $H_2O = 0.04$; $Co_2 = 0.01$; $TiO_2 = 0.77$ Sa. 100.02.

Manganese. Manganese oxide occurs in Ilocos Norte in nodules concentrated in shallow beds. The original home of it has been traced by Smith[13] to small stringers in a recent andesite flow. Manganese occurs in small pockets in the quartz veins in the gold districts of Benguet, Masbate and Camarines.

The Non-metals.

Coal. Coal is found on nearly every island of the Archipelago. The principal localities are Batan Island, Albay Province, Luzon; near Compostela and Danao, Cebú; near Cataingan, Masbate; near Bulalacao, Mindoro; near Sibuguey Bay, Mindanao and near Burdeus, Polillo. The coal measures belong to the Tertiary period. The coal is sub-bituminous.

The production in 1908 was 77,166 metric tons.

There are only two producing mines at present and these are both on the little island of Batan.

Coal from Batan Island:		from Cebú:
Vol. comb.	39.98	36.44
Fixed carb.	48.80	54.58
Ash	5.70	4.12
Moisture	5.74	4.86
Sulphur	0.66	1.88
	100.88	101.88

Petroleum. Oil seeps have been noted at two places on the Island of Cebú, two in Leyte, four on Tayabas Peninsula and one in the Cotabato Valley in Mindanao. Three oil wells have been drilled but as yet no appreciable flow has been obtained. One well in Cebú reaches a depth of 1100 feet. The oil occurs in Tertiary sandstones and shales.

Phosphate. Small deposits of guano in limestone caves, but no rock phosphates, have been found. One small deposit of apatite crystals has been found in Ilocos Norte.

Sulphur. Small deposits, scarcely large enough to be of commercial value, occur in Leyte, on the Island of Biliran, Mount Apó in Mindanao, and a few other scattered localities. On the Island of Camiguin, in the Babuyanes group, Mr. Ferguson found a fair deposit.

Salt. No natural salt beds are yet known in the Philippines. Some very salty springs occur in several provinces, principally in the Mountain Province of Luzon.

Asbestos. Asbestos of the anthophyllite and baltimorite varieties occur in Ilocos Norte, but as yet only occasional veinlets of chrysolite. There is no production and but little development work.

Clay. Crude ware, pelones, cooking pots, brick and tile, all burning red and unglazed, are made throughout the Islands. Some glazed ware has been made, using common salt glazing, but little fine faience has been attempted.

In Laguna Province some deposits of kaolin are located, but they are not worked now. Orthoclase feldspar and sand suitable for glass making have been found in a very few places. Good glass sand has recently been discovered in Ambos Camarines.

Mineral waters. The Philippines abound in good mineral waters. The two principal springs are at Sibul (Bulacán) and Los Banos (Laguna). 268,440 liters were bottled and sold in 1908.

Artesian wells. The Bureau of Public Works has drilled, and is drilling, a great number of wells throughout the Islands, with splendid success. Most of these are located in the recent formation of the central plain of Luzon. The drilling of these wells, thus affording a supply of pure water, has already had a remarkable effect for the better on the health of the native population.

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